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LONG TERM, LOW TEMPERATURE BIOCHEMICAL OXYGEN DEMAND STUDIES

by

ROBERT NEIL BRIGGS

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

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UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled LONG TERM, LOW TEMPERATURE BIOCHEMICAL OXYGEN DEMAND STUDIES submitted by ROBERT NEIL BRIGGS in partial fulfilment of the requirements for the degree of MASTER OF SCIENCE.

A B S T R A C T

LONG TERM, LOW TEMPERATURE BIOCHEMICAL OXYGEN DEMAND STUDIES

The process of biological oxidation has received considerable attention by engineers and bacteriologists. Most studies have been conducted for warmer climatic conditions and are not directly applicable to the colder conditions experienced in Alberta, especially during the winter months. To further the understanding of the biodegradation of organic matter in the 0°C to 5°C range several low temperature, long term tests have been conducted and compared to the standard 20°C tests. Two different types of containers were investigated for use in conducting long term B.O.D. tests.

A review of the B.O.D. theory, carbonaceous and nitrogenous stages; the biological processes encountered in the breakdown of organic matter; the use and determination of the B.O.D. values and their use in stream sanitation has been shown.

The deoxygenation rate constant "k" was shown to decrease from 0.139 per day at 20°C to 0.096 and 0.043 per day for 5°C and 0°C respectively. Arithmetic and semi-log plots, showing the progression of B.O.D., indicated a decrease in the ultimate first stage B.O.D. "L" with temperature; however, the calculated values of "L", on the samples tested, were too erratic to permit this generalization.

In this test series a value of 26,800 calories was found for the constant "E" in Arrhenius' Equation, which permits the conversion of "k" values in the 0°C to 5°C range.

Various lengths of "lag periods" were found in the low temperature tests and it has been recommended that low temperature "acclimatized" seed be used in future low temperature tests to attempt to reduce the lag period.

Nitrification studies show the occurrence, length, and degree of the ammonia, nitrite and nitrate stages. No nitrification was found to occur at the lower temperatures, and in the acidized samples within a period of seventy days. At 20°C nitrification did not commence until the eleventh or twelfth day.

The change in rate of the B.O.D. reaction in the North Saskatchewan River, due to the provision of secondary sewage treatment at Edmonton, was demonstrated. Secondary treatment affected a lower B.O D. curve, lower and slightly earlier nitrification stages.

Two materials for the construction of flexible containers for conducting long term B.O.D. tests were investigated. Mylar bags proved unsuccessful, however if preformed bags were available the study should be continued. A piston and cylinder arrangement of perspex proved a simplified means for conducting the long term tests, however with its use higher B.O.D. values, lower deoxygenation rates, and higher ultimate first stage B.O.D. values were obtained over that when using B.O.D. bottles.

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G L O S S A R Y

1. ADP - Adenosine Diphosphate Nucleotide

2. ATP - Adenosine Triphosphate Nucleotide

3. B.O.D. - Biochemical Oxygen Demand

4. DPN - Diphosphopyridine Nucleotide

5. FAD - Flavin Adenosine Dinucleotide

6. **k** - Deoxygenation Rate

7. L - Ultimate First Stage B.O.D.

8. y - B.O.D.

9. Y_t - B.O.D. at Time "t"

10. t - Time

CHAPTER I

BIOCHEMICAL OXYGEN DEMAND

I-1 INTRODUCTION

The Theory of Bio-Degradation of Sewage, although originally based on suppositions which were basically correct, have in the past decade received considerable attention by engineers and microbiologists. This has resulted in considerable understanding into the various stages of the degradation of organic matter, and the self purification of streams. Most of this research has been in areas of warmer climatic conditions, consequently much of the printed data is not applicable in Alberta.

The object of the thesis is basically to further the understanding of the bio-degradation of organic matter in colder climates and to ascertain a simple method of running B.O.D.'s for long term tests.

Specifically, the following avenues will be investigated:

1) Determination of the deoxygenation rate constant for the first stage B.O.D. at temperatures of 20°C and in the 5°C to 0°C range, with the possible formulation of a temperature correlation equation.
2) An experimental approach to the nitrification stages to determine the time, length and degree of nitrification at the standard temperature of 20°C, and also between 5°C and 0°C.

3) The effect on a river's B.O.D. curve when primary sewage treatment is increased to secondary sewage treatment.
4) Use of large volume, flexible containers for conducting long term B.O.D. studies.

The biochemical oxygen demand (B.O.D.) is one of the main parameters used when dealing with any sewage or pollution problem. It is the amount of oxygen consumed in the metabolism of unstable mico-degradable organic matter by micro organisms (mainly aerobic bacteria), within a standardized time and at a definite temperature. A five day, 20°C B.O.D., which is the standard test, is therefore the amount of oxygen, in parts per million, utilized (oxygen demand) in the aerobic decomposition of organic matter in five days at a temperature of 20°C.

The B.O.D. test through long usage has often been taken as being an absolute quantitative test. Considering the numerous complex reactions undertaken by, and the various factors which can affect the activity of the bacteria, the test assumes qualitative properties only. By standardizing the test procedure and removing many of the variables which affect it, the test becomes semi-quantitative and useable. The B.O.D. test will not, for example, show any oxygen demand for organic material which is not readily or easily metabolized by bacterial action.

The oxygen demand for sewage treatment plant effluents, industrial wastes, or streams is exerted by microbial action on carbonaceous organic material and on nitrogenous material. Heterotrophic bacteria utilize the organic carbonaceous compounds through oxidation

and reduction reactions for their source of carbon and energy, as well as requiring free dissolved oxygen (aerobes). Autotrophic bacteria utilize carbon dioxide or carbonates as a source of carbon and obtain their energy from the oxidation of inorganic nitrogenous (protein) compounds, for example ammonia and nitrites.

The utilization of the carbonaceous material is known as the first stage B.O.D. or Carbonaceous Stage. The first stage B.O.D. is followed by the utilization of nitrogenous material resulting in the second stage B.O.D. or Nitrification Stage.

An oxygen demand may also be exerted by certain chemical reducing compounds such as ferrous iron, sulphite or sulphide, which react with molecular dissolved oxygen.

The rate of biochemical oxidation is thought to be proportional to the remaining concentration of the unoxidized substrate, measured in terms of oxidizability (Steel, 1960). It is affected by temperature in that higher rates occur at higher temperatures and lower rates occur at lower temperatures.

I-2 Importance of B.O.D.

The B.O.D. test has many important applications and uses in the field of sanitation and is the principle test applied to sewage and industrial wastes. Some of these applications are as follows:

a) As a common parameter for the measurement of the strength of sewage or industrial wastes,

b) As a measurement of treatment plant efficiencies.

c) As a means for determining the amount of pollution (organic matter) added to, or in a stream, as well as providing design criteria for the amount of organic waste which can be added to a stream and still maintain desired dissolved oxygen levels in the stream.

d) In the design of sewage and waste treatment facilities, i.e. settling basins, digesters, trickling filters, activated sludge, tanks, etc., as a design criteria.

e) As a control for the determination of stream and effluent standards for stream pollution regulatory agencies.

f) The establishment of sewage charge rates.

g) It is the only determination that gives a measure of the amount of biologically oxidizable organic matter present that can be used to determine the rates at which oxidation will occur.

I-3 B.O.D. AND THE RIVER

When organic matter is introduced into a river, it imparts an oxygen demand on that river through increasing the biological activity. All bodies of water are capable of withstanding limited quantities of organic matter. This ability to oxidize organic matter, without creating offensive conditions, is limited due to the low solubility of oxygen which in fresh water may range from 14.6 ml./litre O_2 at 0°C to about 7 ml./litre O_2, at 35°C under 1 atmosphere of pressure. The solubility varies directly with atmospheric pressure at any given temperature complying with Boyle's Law.

Dissolved oxygen is required in a river to prevent it from becoming septic and objectionable. The dissolved oxygen content should be sufficiently high to maintain conditions favourable for the normal population of fish and other aquatic organisms. Where a river is used for a domestic water supply or for recreational activity, high dissolved oxygen levels are required.

Most of the work done in pollution studies deals with river conditions in which low flows occur in the summer months. Biological activity increases with temperature (within limits), therefore the bacteria will exert a higher oxygen demand, during the warmer temperatures, and at a time when the river cannot provide sufficient dilution of the waste. In Alberta the problem is mainly that of endeavouring to maintain the required dissolved oxygen level during winter months when there is an ice cover, therefore no reoxygenation, and at which time the low flows also occur. Although the saturation value for oxygen is higher at lower temperatures, the reoxygenation rate wherever reoxygenation is possible is much slower. Ice cover, being prevelant for four or five months of the year, is the critical reason why any organic loads imposed on any stream must be carefully controlled to maintain aerobic conditions in the river. In Alberta this sort of control is provided.

The rate or velocity of the biological deoxygenation is an important parameter in stream pollution control. The deoxygenation rate is calculated by observing daily values of the B.O.D. The B.O.D. test is normally conducted by adding measured portions of

waste to specially prepared and aerated water (dilution water). This mixture is added to a 300 ml. glass bottle which is then incubated until the time of test. The depletion of the dissolved oxygen between the original and test time is recorded. From these B.O.D. readings and by the use of the monomolecular equation (Thomas, 1950) the deoxygenation rate can be determined. Knowing the rate of deoxygenation, the ultimate first stage B.O.D. can be calculated. From these values in conjunction with a reaeration rate constant for the river (zero with ice cover), the amount of organic matter which can be added to the river and still maintain the minimum required oxygen levels can be determined.

Most articles on the deoxygenation rate constant have been written for a temperature range of 5°C to 37°C, and mainly at 20°C. Unfortunately, little work has been done at the lower temperatures of 5°C to 0°C, at which temperatures Alberta rivers are for six months of the year. (TABLE I-1)

Discrepancies between the calculated deoxygenation rate constants, as determined by the Standard Method (1961) of deriving B.O.D.'s, and the actual deoxygenation rate constants based on measured dissolved oxygen levels in the river are the rule rather than the exception. An example of this is the North Saskatchewan River between Edmonton and Lloydminster. FIGURE 1-1 shows the dissolved oxygen levels in the river for the month of December 1965 (average four sample periods) (Sanitary Engineering) and for January 5 and 7, 1966. The large discrepancy between the calculated deoxygenation rate constants and actual measurements on the river are clearly indicated on FIGURE 1-2. The B.O.D.

TABLE I-1

NORTH SASKATCHEWAN RIVER TEMPERATURES

Edmonton Water Treatment Plant

Month	Temperature °C Low	High	Average
January	0.0	0.6	0.0
February	0.0	0.6	0.0
March	0.0	0.6	0.0
April	0.6	7.7	1.7
May	8.3	15.0	12.7
June	9.9	16.1	13.3
July	14.0	21.1	17.2
August	12.7	21.1	18.3
September	7.2	13.3	9.4
October	5.6	8.9	7.7
November	0.0	4.4	1.7
December	0.0	0.6	0.0

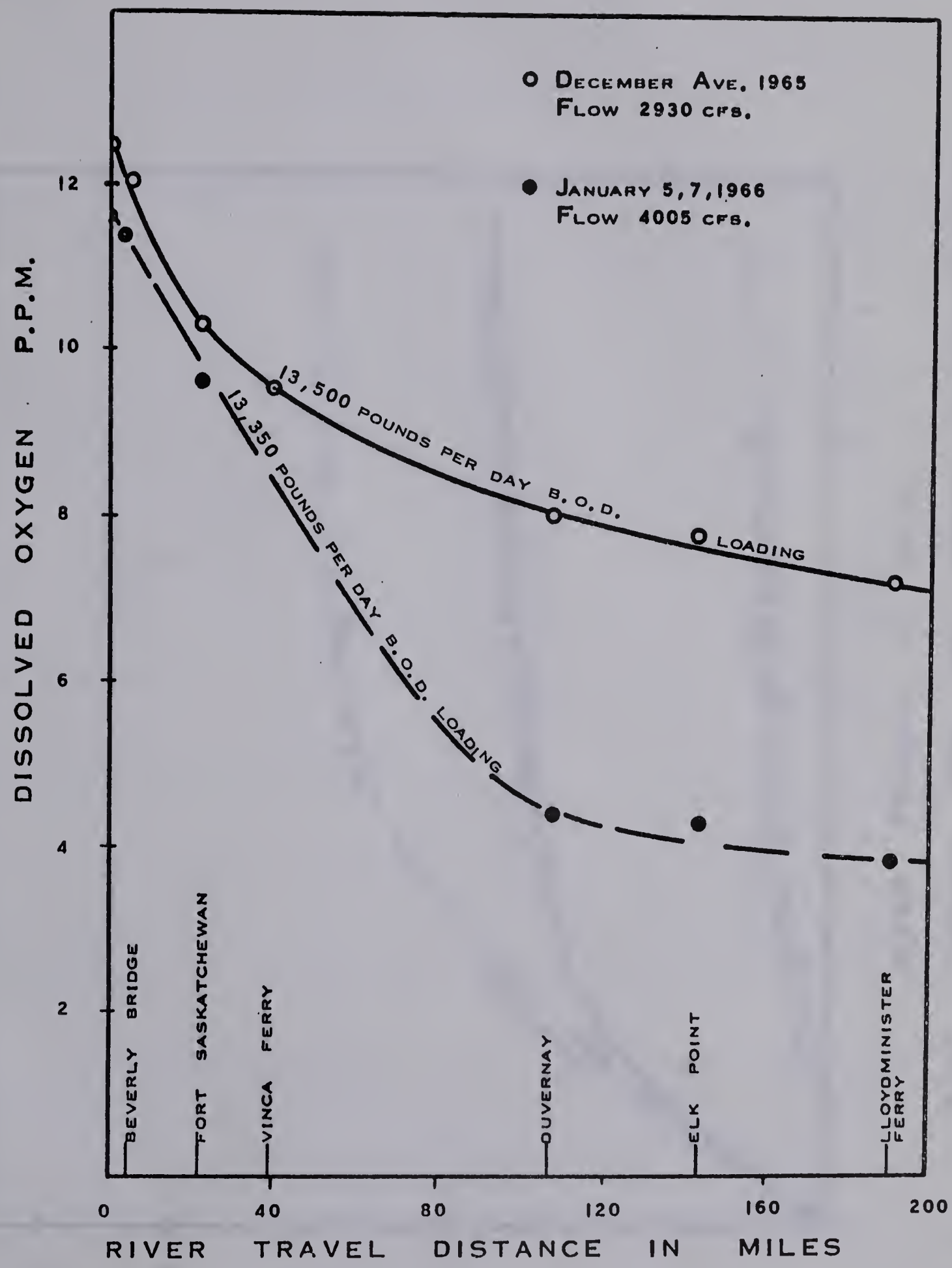
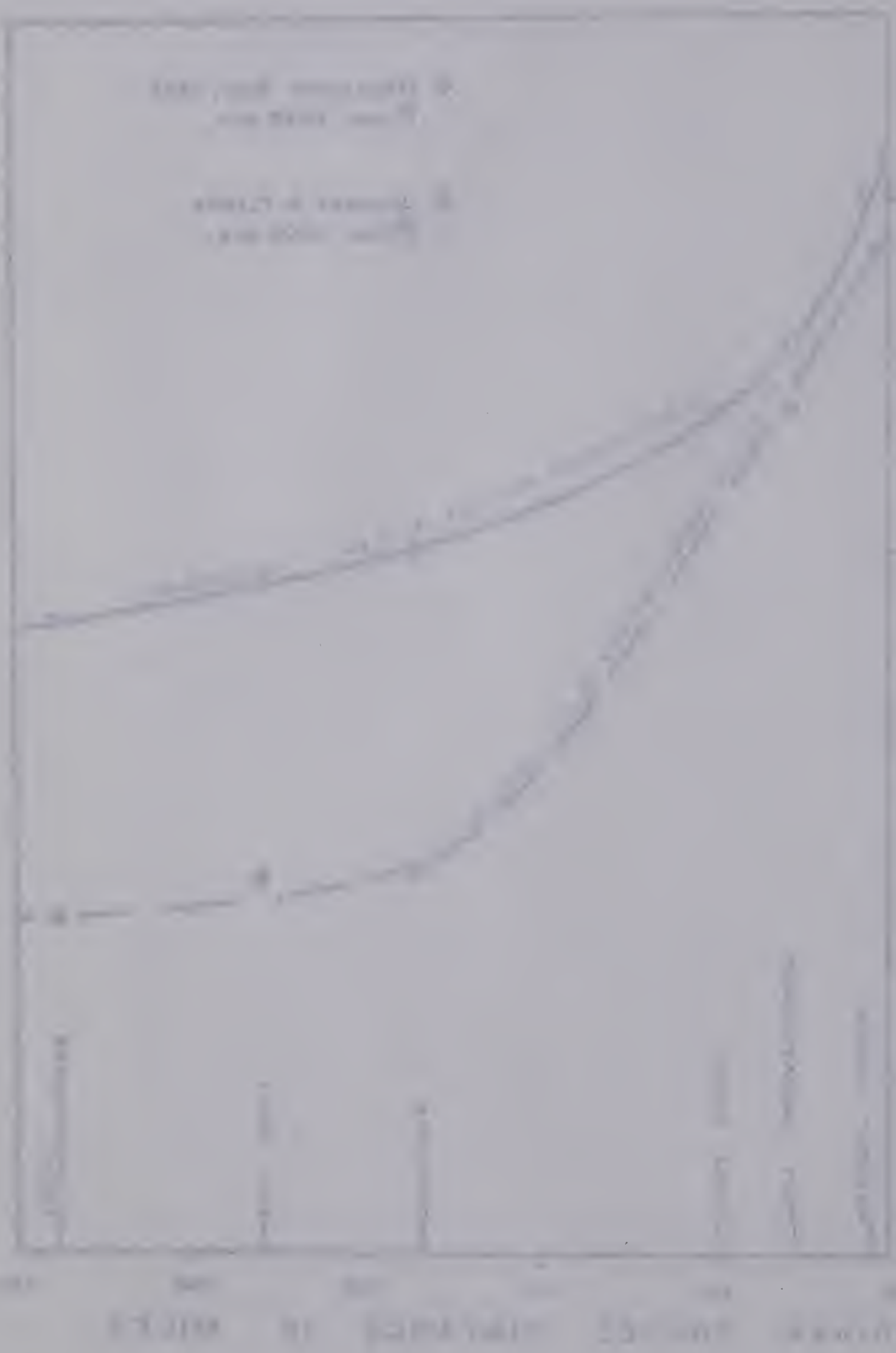


FIGURE: 1 - 1 OXYGEN DEPLETION IN THE NORTH SASKATCHEWAN RIVER AT VARIOUS STATIONS BELOW EDMONTON



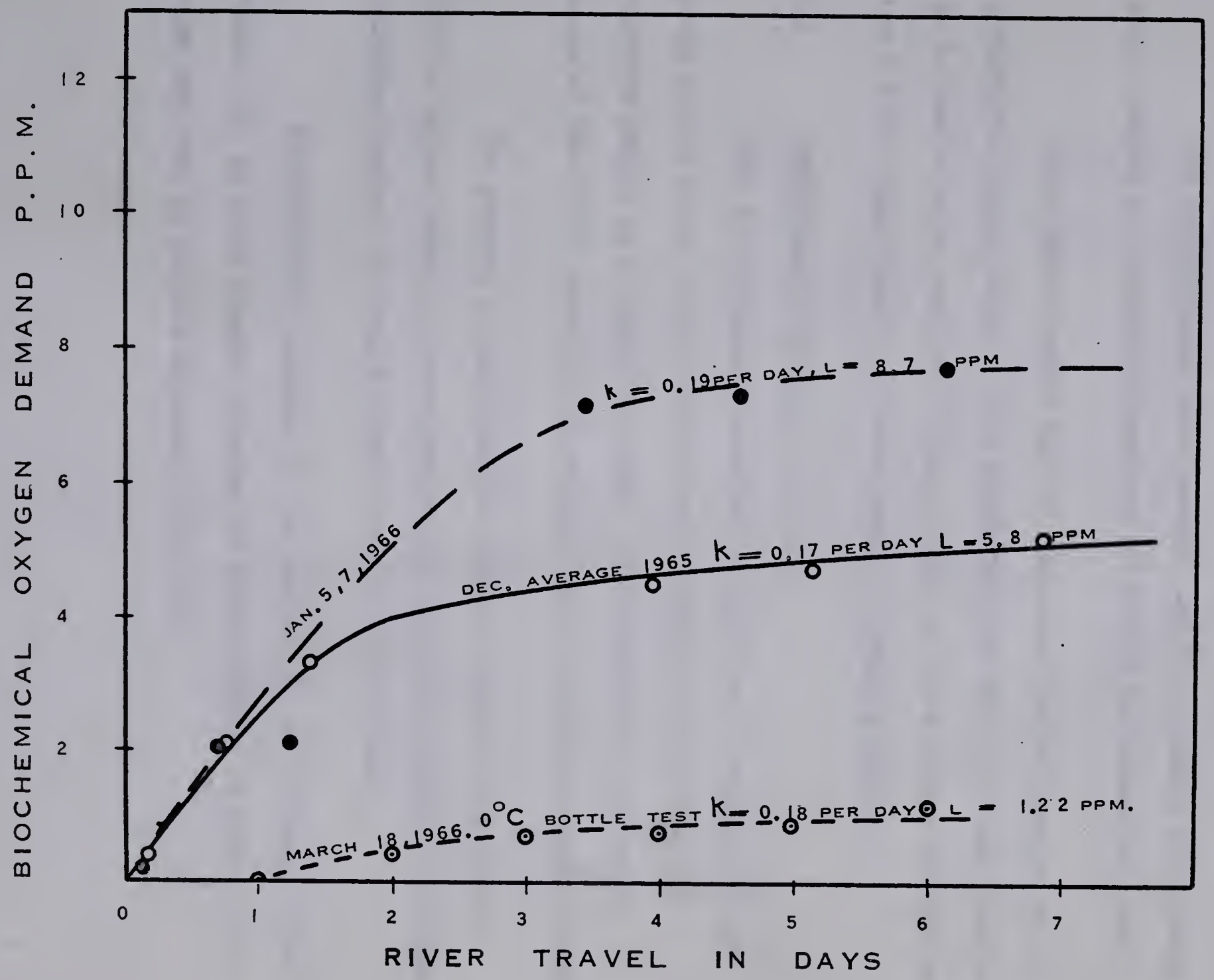
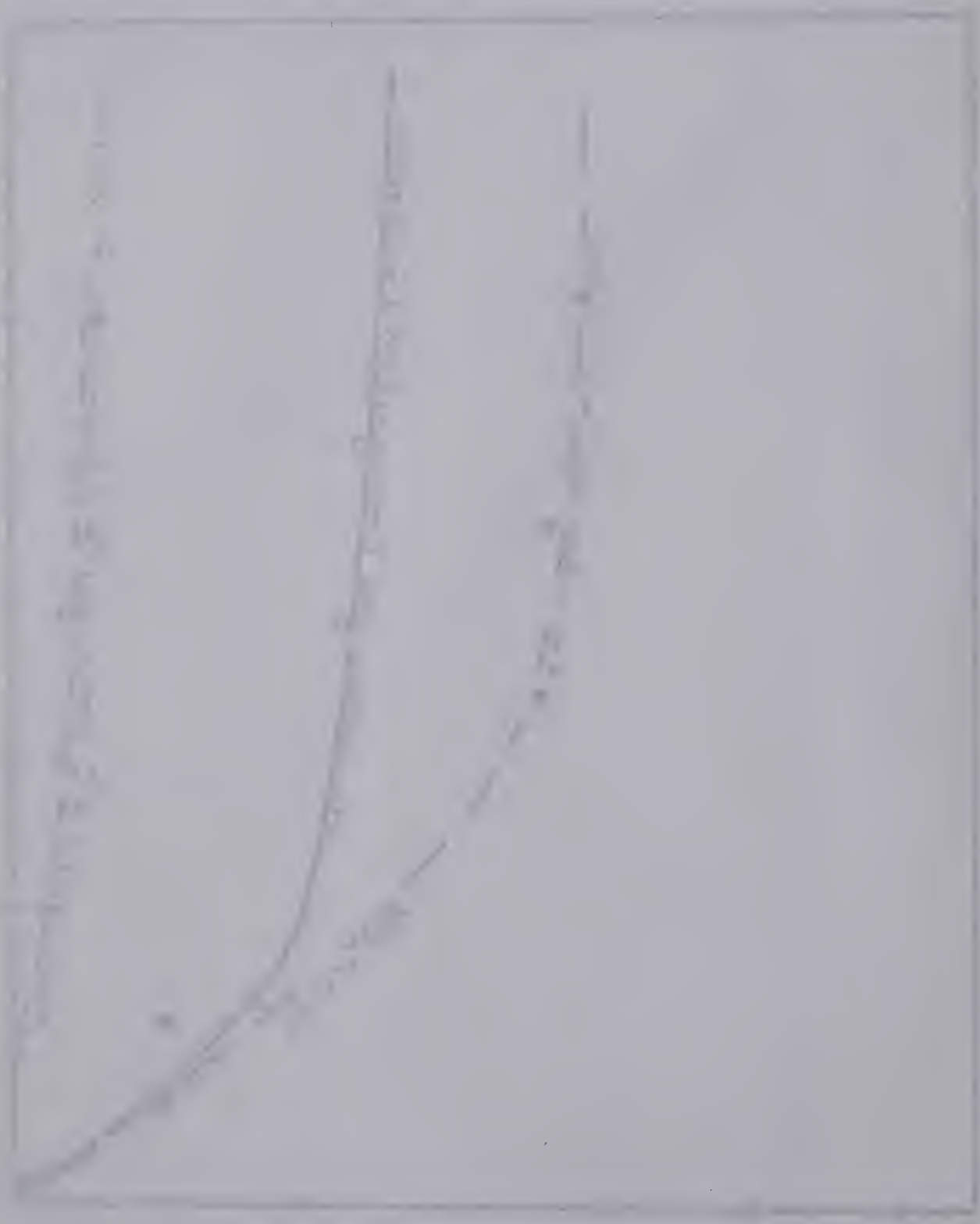


FIGURE: 1 – 2 B.O.D. CURVES FOR THE NORTH SASKATCHEWAN RIVER



curves are shown for the dissolved oxygen measurements as well as for a sample from Fort Saskatchewan which was obtained on March 18, 1966, and incubated at 0°C. The calculated rate constants are shown on each graph and have been corrected for differences in the flow.

The deoxygenation rate constant and the ultimate first stage B.O.D. values are extremely important parameters in stream pollution.

Other factors which must be considered in the computation of a dissolved oxygen balance for a stream are the type of stream, whether it is fast or slow, shallow or deep; affect of river bottom deposits on the B.O.D.; river flows; and the strength of organic matter.

I-4 NITRIFICATION IN THE B.O.D. TEST

Once the carbonaceous matter is fairly well oxidized (first stage of the B.O.D. curve) the bacteria gradually turn to the nitrogenous matter as a source of energy. This results in the second stage of the B.O.D. curve and is referred to as the Nitrification Stage.

The process of nitrification requires oxygen which causes a further oxygen demand on the stream and is therefore important in Stream Pollution Control, if long periods of non reaeration occur.

Nitrification consists of that portion of the Nitrogen Cycle, FIGURE 1-3, in which ammonia nitrogen is first oxidized to nitrite nitrogen and then to nitrate nitrogen. (Rich 1963)

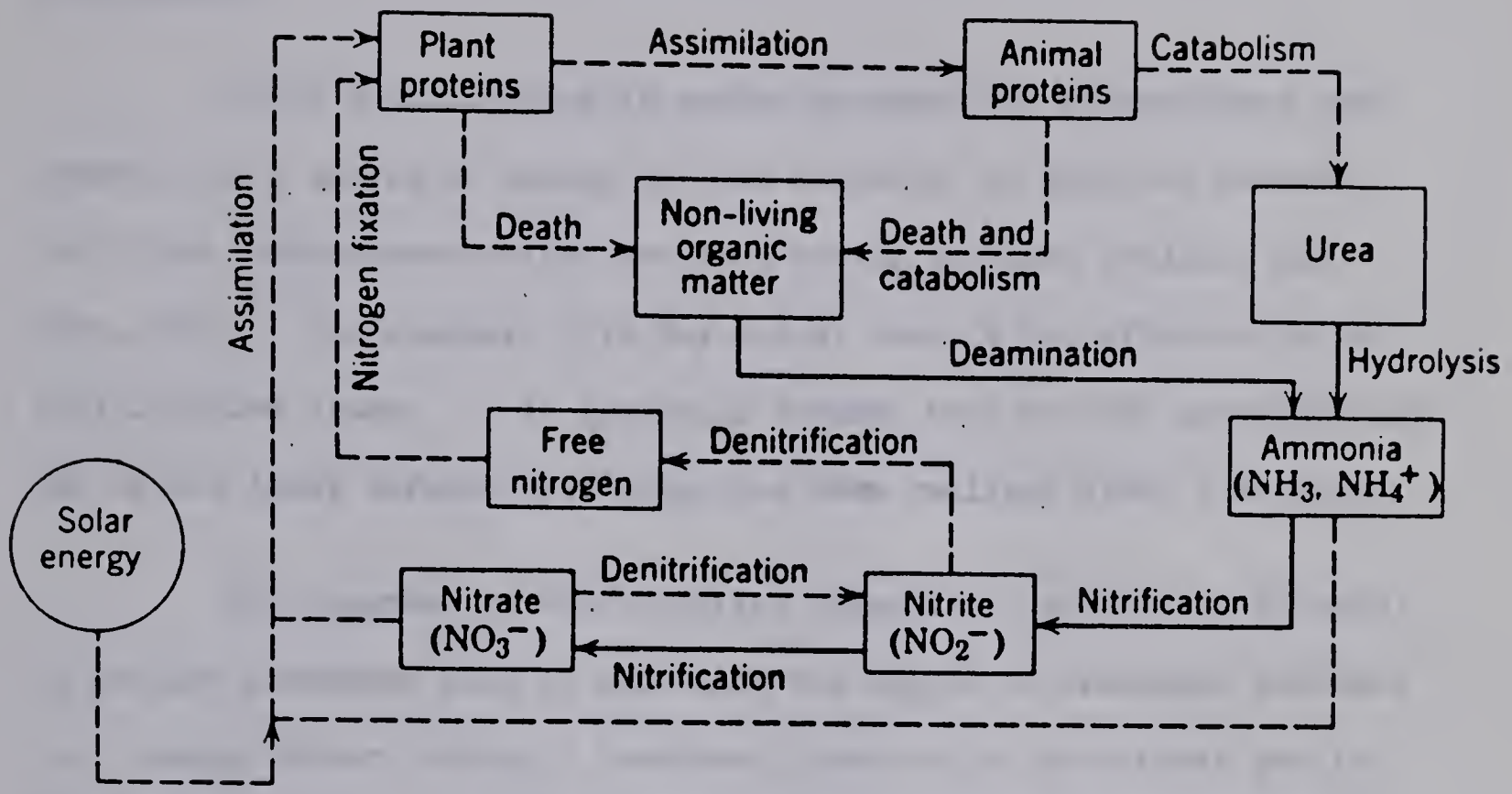
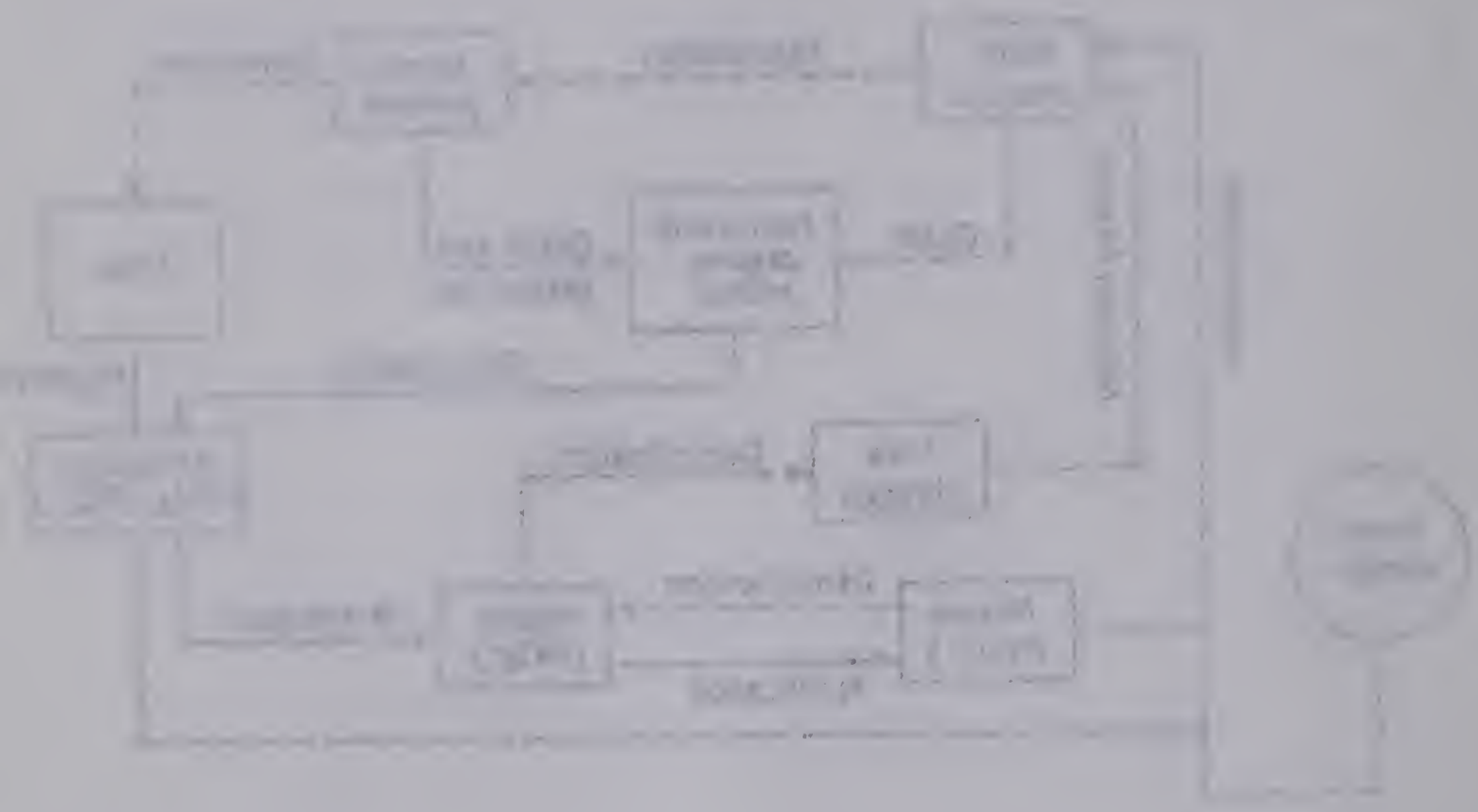


FIGURE 1-3

NITROGEN CYCLE

The microorganisms (bacteria) responsible for the first step in nitrification, that is the oxidation of ammonia nitrogen to nitrite nitrogen, are primarily autotrophic nitrifiers of the Genera Nitrosomonas, Nitrosococcus, Nitrosospira, Nitrosocystis and Nitrosogloea. The Genus Nitrosomonas is the most common and is strictly aerobic, requiring abundant oxygen and is very sensitive to acidity (Frobisher, 1962).



The second step of nitrification is the oxidation of nitrite nitrogen to nitrate nitrogen by the autotrophic nitrifiers of the Genus Nitrobacter.

Since nitrification is second in order (to carbonaceous compounds), as a source of energy for the bacteria, it will not proceed until the carbonaceous matter has been mostly utilized (Pelczar and Reed, 1965). The standard five day B.O.D. test is not affected by the nitrification stage. It is generally assumed that at 20°C approximately 68% of the total carbonaceous stage has been realized after five days.

The progress of nitrification (ammonia to nitrite to nitrate) is another parameter used to determine the degree of treatment provided to a sewage either through a treatment plant or in the natural purification of streams. The presence of nitrate indicates a high degree of oxidation.

The presence of ammonia nitrogen in a water is generally indicative of extremely recent pollution or of fresh sewage. Nitrites indicate recent pollution and that the stream is in the process of recovering. The occurrence of nitrates indicate past pollution and that stabilization of the stream has occurred. If excessive nitrates are evident, aquatic plant life may flourish due to the fertilizer value of the nitrate in the water. This in turn may create a detrimental effect on the water.

The nitrite and nitrate nitrogen constitute an oxygen reserve that will supplement the dissolved oxygen concentration of the receiving waters, if the dissolved oxygen has been eliminated (Fair & Geyer, 1965).

CHAPTER II

BIOCHEMICAL OXYGEN DEMAND THEORY

II-1 General B.O.D. Curve

FIGURE 2-1 shows the curve outlined by plotting the B.O.D. versus time on arithmetic paper. The curve is typical and has been plotted for a sewage (A-3) which is mainly domestic in nature.

The same data is shown replotted on semi-log paper, FIGURE 2-2 for comparison, and for the further understanding of the deoxygenation process. With the semi-log plot the observed B.O.D. data plots as a series of straight lines, each of which represent a biological phenomenom as explained later in the chapter.

II-2 The first stage B.O.D. is the "carbonaceous stage" and is shown in FIGURE 2-1. It is this portion of the curve which has received the most study, and is the most useful as it includes the five day B.O.D. period. It is also the portion of the curve on which the monomolecular reaction $y = L(1-10^{-kt})$ is based for determining the deoxygenation rate constant "k". (B-1)

As previously indicated (I-1) carbonaceous material, which is generally considered to be the various forms of carbohydrates, is metabolized by heterotrophic bacteria for their source of energy and carbon. Basically, energy is required by the bacterial cell if it is to remain

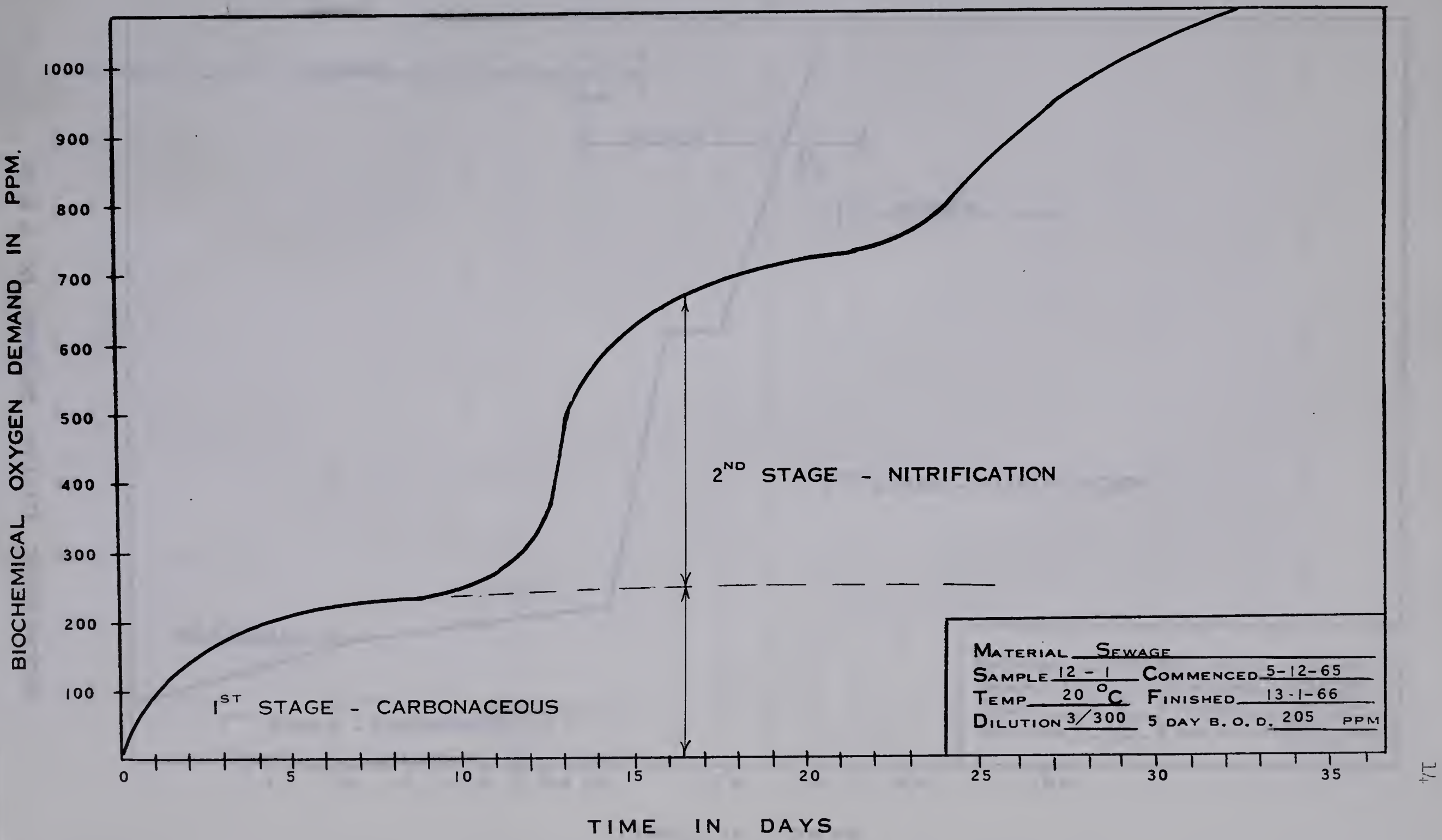
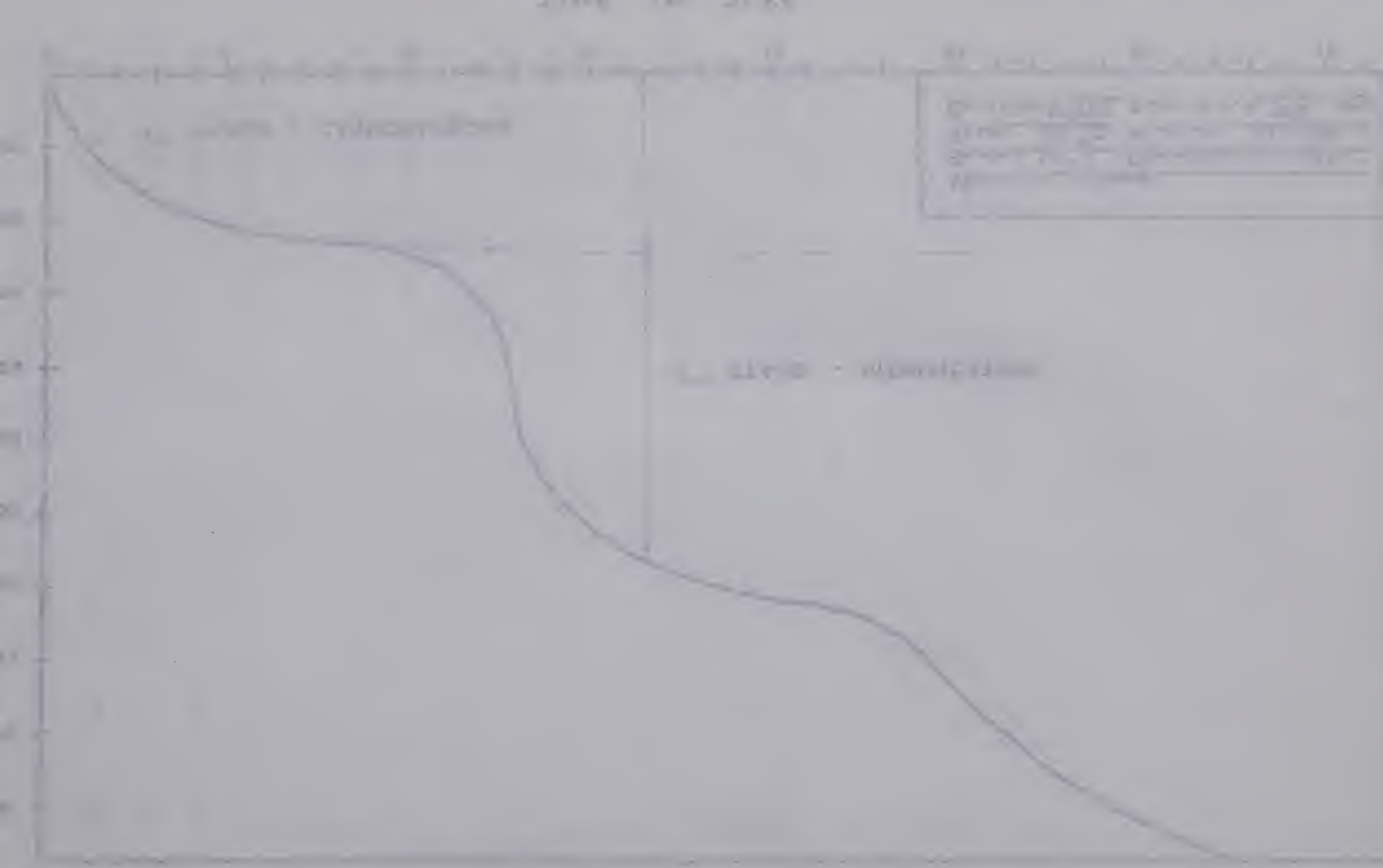


FIGURE: 2 - 1 NORMAL B.O.D. CURVE " ARITHMETIC PLOT"



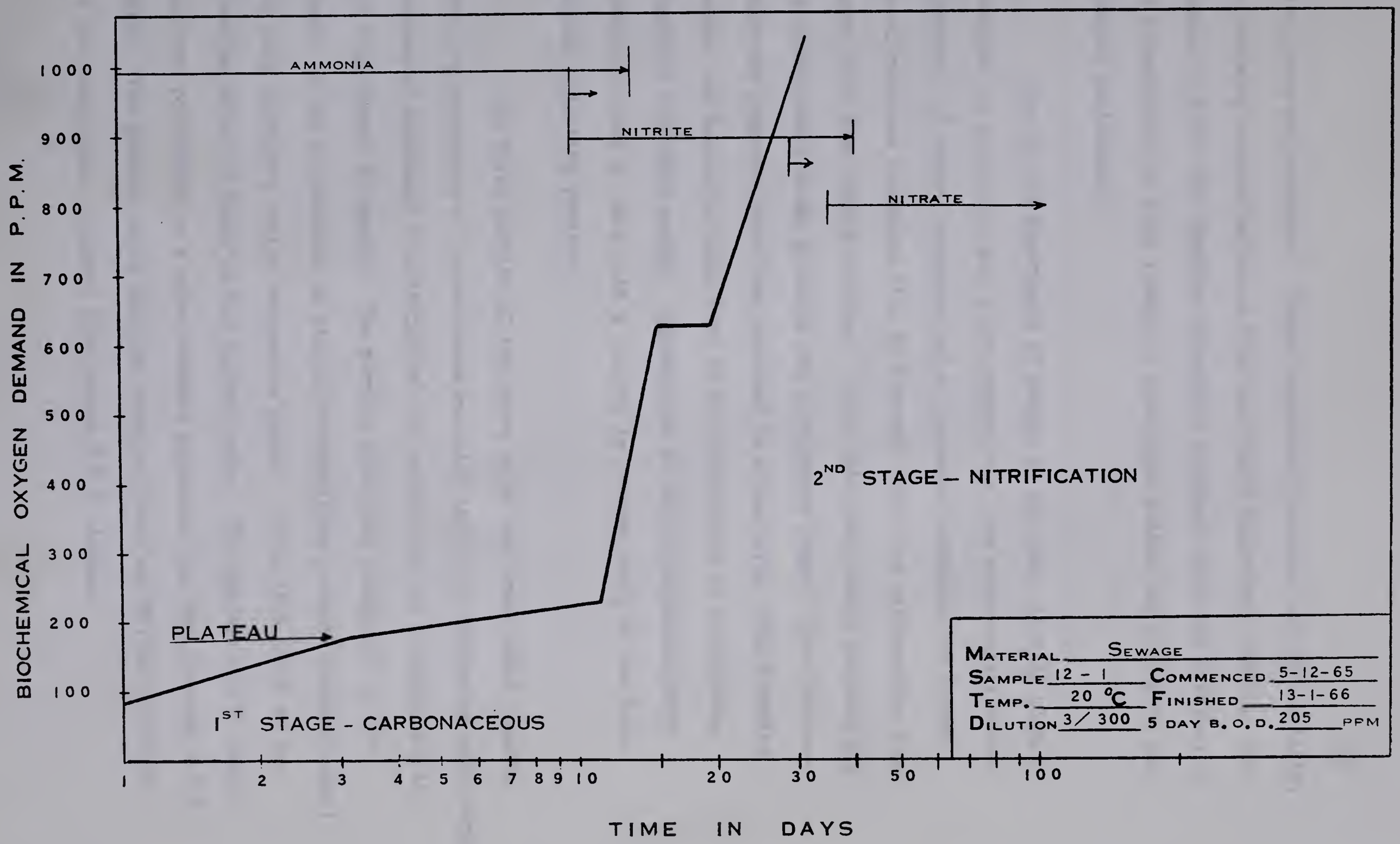
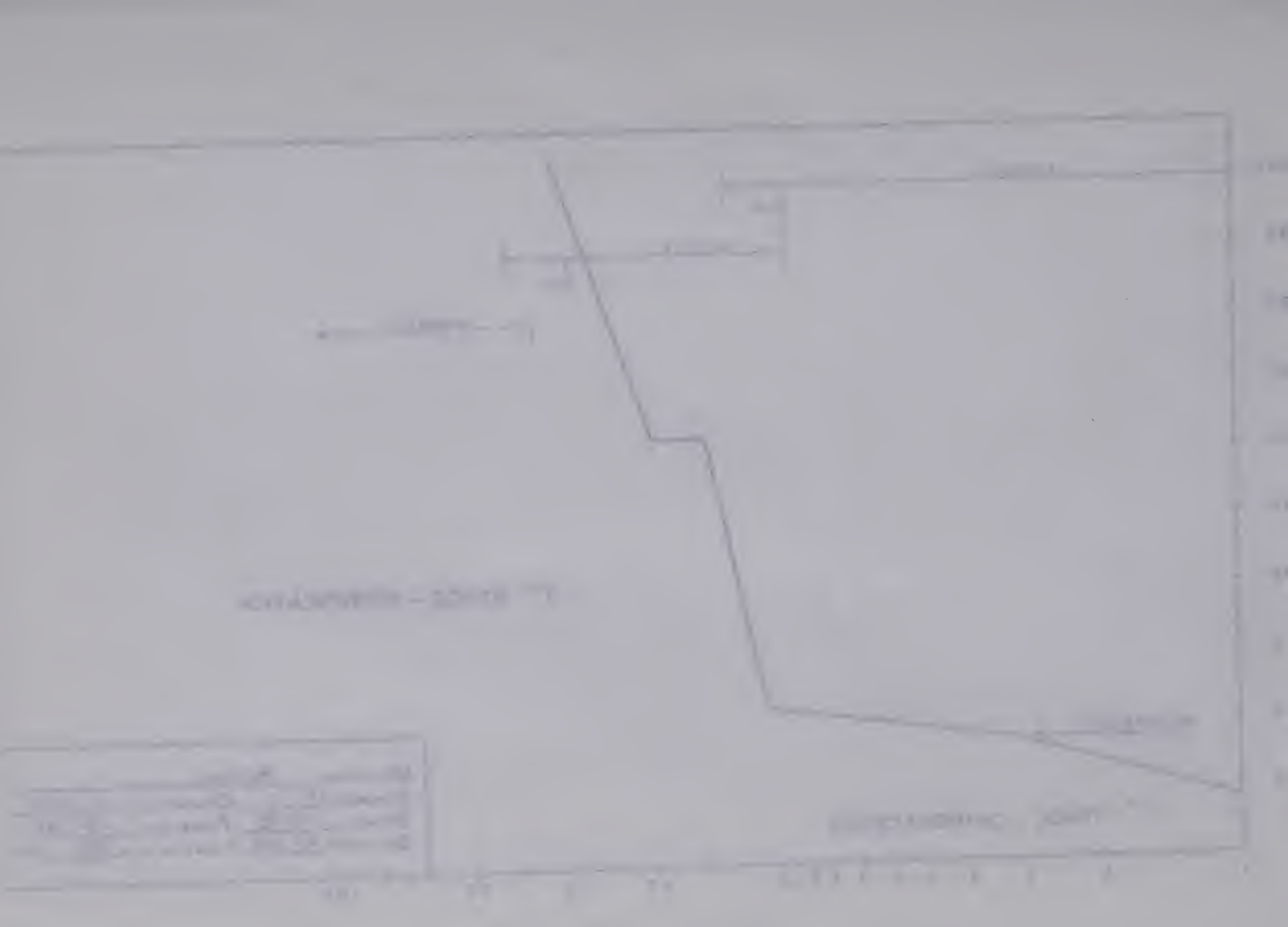


FIGURE: 2 - 2 B. O. D. CURVE "SEMI - LOG"



alive, grow and reproduce. Energy requiring functions are for motility; synthesizing complex molecules from the simple molecules, for cell protoplasm; and for the numerous "transport systems" which are involved in the accumulation of high levels of substances within the cell from the external environment.

Due to the importance of energy to the cell, it will always endeavour to accumulate and store energy over it's other requirements. Therefore, if carbon compounds and nitrogenous compounds are present, the nitrogenous compounds will be "spared" until the carbonaceous compounds have been mainly oxidized. It is this point which explains why the carbonaceous stage precedes the nitrogenous stage. Once the carbonaceous compounds have been oxidized to a low level, thus becoming scarce, the bacterial cells turn to the oxidization of nitrogenous compounds for their energy. Examination of the carbonaceous curve FIGURES 2-1 and 2, show that a plateau is reached early in the biological oxidation process.

The first portion of the curve up to the break point results from the conversion of carbonaceous material into cell substances with varying degrees of synthesis (dissimilation), at which time the bacteria are in the "log phase" of growth. The portion after the breakpoint is the result of the utilization of stored decomposition products (assimilation), and cell substance during endogenous growth. It is this point of inflection which is known as the plateau value. The plateau B.O.D. value has been postulated as a more accurate parameter than the five day B.O.D. value. The plateau value has been found by Busch and Myrick to be 41% of the theoretical ultimate first stage B.O.D. demand.

II-3 Second Stage Nitrification

Nitrification is the second stage of the B.O.D. curve and proceeds in two definite steps, these being the oxidation of ammonia nitrogen to nitrite nitrogen; and from nitrite nitrogen to nitrate nitrogen. Each step has two slopes which represent dissimilation, the conversion of nitrogenous matter (proteins) into cell substance with varying degrees of synthesis; and assimilation, the use of stored products of dissimilation. The oxygen demand is exerted by the various biological oxidations of ammonia to nitrite.

The first stage of nitrification consists of the dissimilation of the ammonia through oxidation reactions to nitrite, and secondly by the assimilation of the products of dissimilation by the bacterial cell. During the first stage the bacteria are growing in the "log phase" of growth and in the second stage they are in the "endogenous phase" of growth (See FIGURE 1-2).

Members of the Genus Nitrosomonas are the most important in the oxidation of ammonia to nitrite. They are described in Bergey's Manual as:

"Nitrosomonas europaea - Rods, 0.9 to 1.0 by 1.1 to 1.8 microns, occuring singly, rarely in chains of three or four. Possess a single Polar flagellum three or four times the length of the rods, or rarely one at either end.

"Aerobic, strictly autotrophic"

or as:

"Nitrosomonas monocella - Ovoid rods 0.6 to 0.9 microns, often occuring

in pairs. Young cells nearly spherical. Motile by a single polar flagellum three or five times as long as the rod. Gram positive (Nelson), found Negative by H. T. Conn.

"No growth in nutrient broth, nutrient agar, nutrient or plain gelatin, plain or litmus milk, glucose or plain yeast water, or on potatoes.

"Even low concentrations of organic matter will completely inhibit the initiation of growth. Plant extracts are toxic.

"Free CO_2 and O_2 necessary for growth.

"Optimum pH 8.0 to 9.0. Poor growth below pH 7.0. Some growth above pH 9.0.

"Optimum temperature for growth and oxidation 28°C Aerobic, strictly autotrophic."

The second phase of nitrification, as in the first, proceeds at two definite rates, these being the dissimilation of the nitrite and its subsequent oxidation to nitrate followed by the assimilation of stored products. Except for the oxygen utilized for the endogenous respiration of the bacteria, the total oxygen demand would theoretically be obtained at the end of this phase.

Members of the Genus Nitrobacter are the most important in the oxidation of nitrite to nitrate. They in turn are described in Bergey's Manual as:

"Short non motile rods with gelatinous membrane, 0.6 to 0.8 by 1.0 to 1.2 microns. Do not stain readily. Gram-negative.

"Can be cultivated on media free of organic matter. Sensitive to certain organic compounds.

"Washed agar colonies: In 7 to 10 days very small, light brown, circular to irregular colonies, becoming darker.

"Washed agar slants: In 7 to 10 days scant, greyish streak.

"Inorganic solution medium: After 10 days flocculent sediment. Sensitive to ammonium salts under alkaline conditions.

"Nitrite is oxidized to nitrate.

"Aerobic.

"Strictly autotrophic.

"Optimum temperature, between 25°C and 28°C."

The rate of deoxygenation of the ammonia to nitrite should be three times that of the nitrite to nitrate due to the oxygen requirement as shown in the balanced chemical equations (II-4).

II-4 Metabolism

Metabolism (McKinney 1962; Carpenter 1961) denotes all the organized chemical activities performed by the cell and are of two main types, the first being dissimilation or catabolism which is the breaking down or degradation of the substrate. These chemical reactions are mainly energy yielding reactions from which the cell converts Adenosine Diphosphate Nucleotide (ADP), through enzymatic reactions, into a high energy phosphate bond, Adenosine Triphosphate Nucleotide (ATP) which is stored for latter use; and secondly assimilation or anabolism which is the building up or synthesis of material by the cell. These chemical reactions are generally energy-requiring reactions for which energy is obtained from ATP. ATP is consequently converted back through enzymatic reactions to ADP with the subsequent release of energy.

Hetertrophic bacteria generally derive their energy by aerobic degradation of organic compounds (catabolism and anabolism of carbohydrates) through biological oxidations. Complete oxidation, through numerous enzymatic reactions of a carbohydrate, provides a high degree of energy for the cell. The oxidation of glucose is given as an example. (Pelczar 1965)

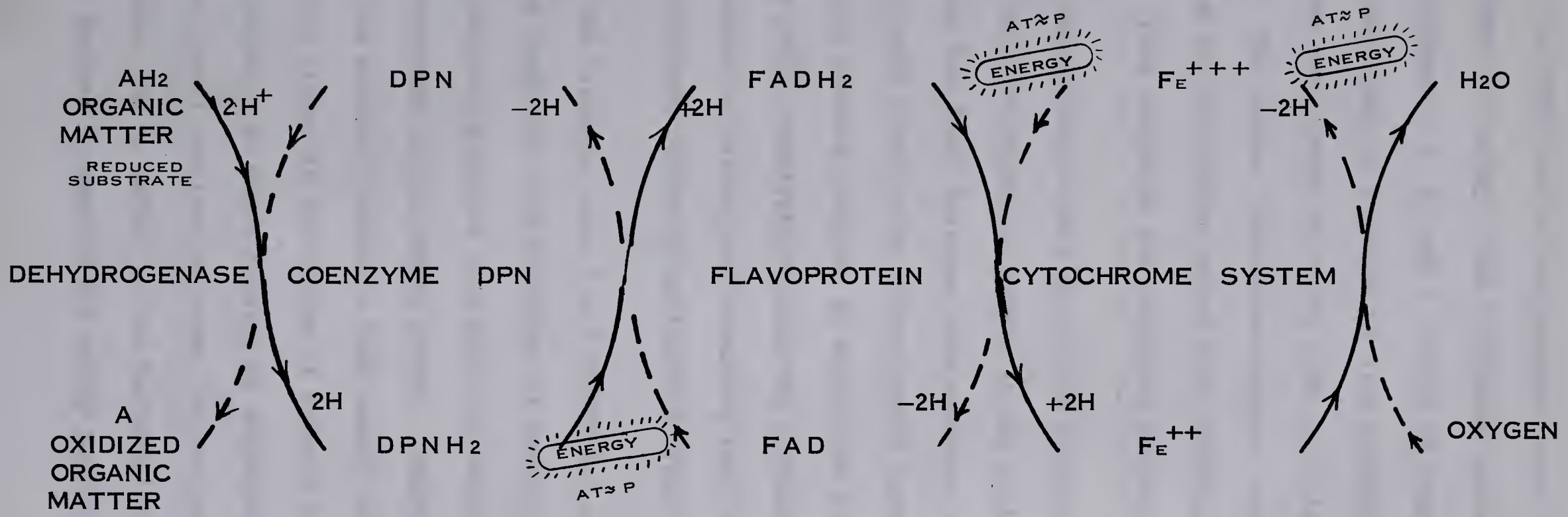
$$\underset{\text{glucose}}{C_6H_{12}O_6} + 6O_2 \longrightarrow 6CO_2 + 6H_2O + 674 \text{ Kg-Cal energy}$$

Biological oxidation reactions are accomplished by dehydrogenation. Dehydrogenation is the removal of hydrogen atoms by enzymatic reactions from a substrate containing it. Oxidation can also be described therefore as a loss of electrons. The substance which accepts the electrons is therefore reduced (a gain of electrons).

Oxidation can be illustrated by the hydrogen transfer system, FIGURE 2-3.

Through enzymatic reaction the organic matter gives up two hydrogen atoms (organic matter now oxidized) to the dehydrogenase coenzyme (coenzyme - that portion of the enzyme which determines what chemical reaction will take place) Diphosphopyridine Nucleotide (DPN), which is responsible for the hydrogen transfer. The DPN, since it has received two hydrogen atoms, is reduced to $DPNH_2$. This yields it's hydrogen atoms to the dehydrogenase coenzyme, Flavin Adenosine Dinucleotide (FAD), which is reduced to $FADH_2$. Energy is released to ADP which converts it by enzymatic reactions into a high energy phosphate bond as ATP.

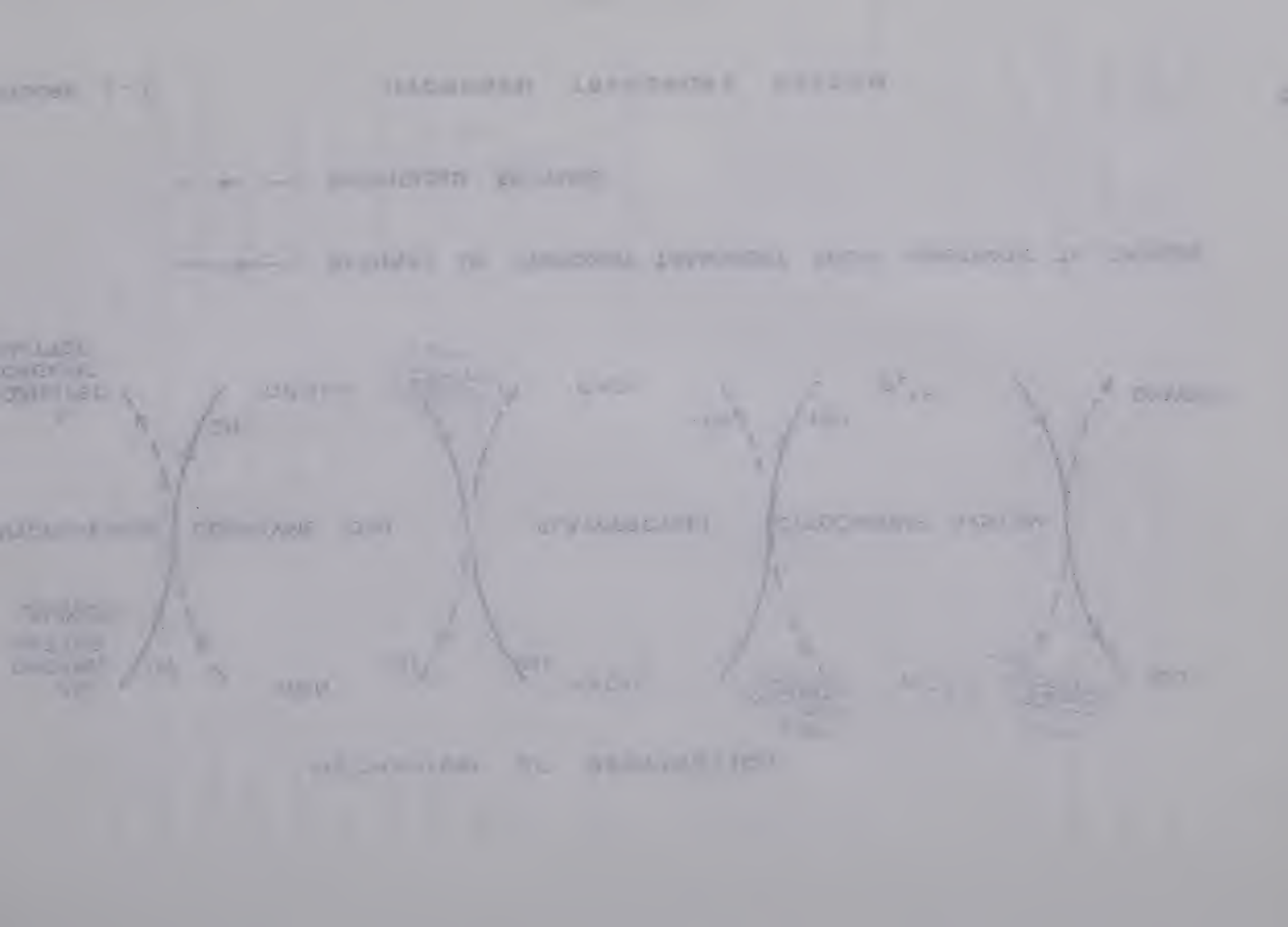
MECHANISM OF RESPIRATION



PATHWAY OF HYDROGEN TRANSPORT FROM SUBSTRATE TO OXYGEN

REOXIDIZED ENZYMES

FIGURE 2 - 3 HYDROGEN TRANSPORT SYSTEM



The $FADH_2$ yields the hydrogen atoms to the cytochrome system, with a release of energy. The cytochrome system consists of at least three cytochromes - a, b, and c - which by enzymatic reactions transfer the hydrogen atoms, by a series of iron oxidation and reduction reactions, to the final cytochrome, at which time there is an additional release of energy. The enzyme, cytochrome oxidase, unites the two hydrogen atoms, from the cytochrome system with elemental oxygen reducing it to water. This completes the oxidation process.

Respiration refers to all the energy yielding oxidation reactions in which molecular oxygen is the ultimate atom acceptor. Oxygen being the final hydrogen atom acceptor is reduced to water. Respiration will continue by heterotrophic bacteria until the carbonaceous matter becomes limited; at which time the autotrophic bacteria will begin active respiration using the carbonates or carbon dioxide as their source of carbon; and obtaining their energy through the hydrogen transport system by oxidizing inorganic nitrogenous compounds.

The nitrogen cycle (I-4) FIGURE 1-3 shows the source of nitrogenous products. The breakdown of protein, through human and animal metabolism, produces urea which is readily hydrolized to ammonium carbonate by the enzyme urease. Unassimilated protein matter, in feces from animals, contain a high amount of organic nitrogen. At death protein stored in the bodies of animals and in plants is converted either aerobically or anaerobically by saprophilic bacteria to ammonia. The bacterial cell requires nitrogen for the assimilation of protein (approximately 70% by weight of the bacterial cell is composed of protein). Enzymes themselves are mainly protein.

Through bacterial action ammonia compounds are oxidized first to nitrite and then to nitrate which is the final end product of the oxidation.

The oxidation of ammonia to nitrite by Nitrosomonas bacteria can be shown by the overall energy equation (Johnson & Schroepfer 1964).

$$2NH_3 + 3O_2 \longrightarrow 2HNO_2 + 2H_2O + \text{energy}$$

The autotrophic bacteria Nitrobacter is the only genus capable of the oxidation of nitrite to nitrate. The corresponding energy yielding equation of the oxidation is:

$$2HNO_2 + O_2 \longrightarrow 2HNO_3 + \text{energy}$$

From these equations it is evident that the oxidation of ammonia to nitrite requires three atoms of oxygen; and the oxidation of nitrite to nitrate requires one atom of oxygen. Each atom of ammonium nitrogen requires four atoms of oxygen in the biochemical oxidation of ammonium nitrogen to nitrate nitrogen.

The net result of nitrification is a further oxygen demand resulting in increased B.O.D. levels. Fortunately, nitrification lags the carbonaceous stage as explained earlier, therefore it's effect on the five day B.O.D. can generally be neglected.

II-5 Summary

The degradation of organic matter is accomplished through a complicated series of biological enzymatic reactions by bacteria.

Aerobic decomposition is accomplished by heterotrophic and autotrophic bacteria respectively for which elemental oxygen is the final hydrogen acceptor. Utilization of dissolved oxygen in water is measureable and is recorded as the oxygen demand of the organics at that time.

Plots of the oxygen demand (Biochemical Oxygen Demand) indicate various phases of the deoxygenation process. These plots can then be used for the determination of the rate of deoxygenation as well as the ultimate carbonaceous B.O.D. demand.

CHAPTER III

AVENUES OF B.O.D. STUDIES

III-1 Deoxygenation Rate Constant

The B.O.D. test was first used by Frankland in 1870, however Phelps, prior to 1912, was the first person to develop an equation for the relative stability of wastes which actually seemed to fit the B.O.D. curve. Phelps' (1948) equation was that of a first order chemical reaction, or as it is often referred to, as the monomolecular or unimolecular equation. The monomolecular reaction is one that exhibits a rate directly proportional to the concentration of a single substance, i.e. as expressed in the differential form

$$-\frac{dL}{dt} = kL \qquad \text{Equation III-1}$$

where, with reference to B.O.D.'s, "L" represents the oxidizable organic matter present, "t" represents time and "k" is a velocity or rate constant which has a unit of time^{-1}, i.e. k per day.

Through integrating and solving equation III-1 (B-1) yields:

$$Y_t = L(1-10^{-kt}) \qquad \text{Equation III-2}$$

where "Y_t" is the B.O.D. in mg./l at any time "t", "L" is the ultimate first-stage oxygen demand for the waste, and "k" is a measure of the rate at which oxygen approaches this limit. Fair & Geyer (1965) states:

"The first-stage B.O.D. has generally been interpreted as a first-order reaction, dependent upon the concentration of oxidizable organic material present but independent of the oxygen concentration, provided that it is greater than a critical value of about 4 mg./l at 20°C for example."

The accredability of the unimolecular theory will not be questioned herein, however it is suffice to say that discrepancies do appear, and many new theories have been proposed (Young and Clark 1965). Many methods of solving the unimolecular equation for the deoxygenation rate constant "k" and ultimate first stage B.O.D. have also been used and proposed (Young and Clark 1965). Thomas' graphical method has been used throughout this thesis.

One of the variables affecting the rate constant is temperature. The rate of reaction "k" increases with an increase in temperature and decreases with a decrease in temperature. In order to determine the lower values of these constants, using the standard 20°C test, Arrhenius' Equation was used (Fair and Geyer 1965) which when integrated between the limits T_1 and T_2 gives:

$$\log_e \frac{k_2}{k_1} = \frac{E(T_2 - T_1)}{RT_1T_2} \qquad \text{Equation III-3}$$

where k is the specific reaction rate

T is the Kelvin temperature

R is the gas constant (1.99 Cal./deg. C)

and E is a constant characteristic of the equation known as the "activation energy". With a knowledge of "E", and one rate constant, at some known temperature, the rate constant at any other temperature can be determined.

By plotting log "k" at a number of temperatures against the reciprocal of the absolute temperature the slope of the best fit straight line is:

$$\text{slope} = \frac{E}{2.303\ R}$$

In place of the values of log "k" the logarithm of any other measured quantities proportional to "k" may be used, for example "L" in equation III-2.

Testing consisted of running daily dissolved oxygen tests in sewage diluted at temperatures of 20°C, 5°C, 4°C, 2°C, 0°C (See IV-1). In order to determine the possible interference of nitrification, two acidized samples were run at 20°C for comparison to the standard 20°C test, and for determination of rate constants and the ultimate first stage B.O.D.'s. This was also repeated for a 4°C series.

III-2 Nitrification Studies

Products of the nitrification stages were measured on standard long term B.O.D.'s, as well as on samples from the cylinder (See III-4). Tests were conducted for ammonia nitrogen, nitrite nitrogen and nitrate nitrogen at temperatures of 20°C, 5°C, 4°C, 2°C, and 0°C.

Results of these tests are indicated on semi-log paper (FIGURE 2-2) as stated in Chapter II and shown in Chapter IV.

In order to determine or show the effect of nitrification on the B.O.D. curve three sets of samples were acidified to a pH of 2.5 by the addition of concentrated sulphuric acid. The sample was held

at pH 2.5 for five minutes at which time it was neutralized with sodium hydroxide. The normal procedure for running B.O.D.'s was then followed (A-1).

III-3 Effect of Secondary Sewage Treatment on the North Saskatchewan River

All bodies of water have the capacity to oxidize waste material added into it. This capacity is directly related to the amount of dissolved oxygen and degree of aeration the water receives. Fast turbulent streams receive more aeration than other bodies of water; they can, therefore, oxidize more organic matter aerobically without creating a nuisance. However, during the winter season the rivers freeze over eliminating reaeration of the water. Due to the ice cover, the river must be able to oxidize any added waste material with only a portion of the dissolved oxygen originally present in the river water if it is to remain aerobic.

Saturation of river water at $0^{o}C$ with respect to oxygen is approximately 13 p.p.m. To maintain the river in a "healthy" condition at least 4 p.p.m. of dissolved oxygen is required. This leaves 9 p.p.m. of dissolved oxygen for the aerobic decomposition of matter. Knowing the river flows, the number of pounds of B.O.D. that can be safely added to the river can be determined.

The City of Edmonton sewage treatment plant, located on the North Saskatchewan River, during the warmer months can, through primary treatment of the sewage, provide an effluent with a B.O.D. that can be satisfactorily oxidized in the river. During winter months however, the

primary sewage treated effluent would create too high an oxygen demand on the river causing it to go septic. To prevent this secondary sewage treatment by the "activated sludge process" is utilized to reduce the organic load from the primary treatment works (by aeration of the primary effluent followed by secondary settling) to a level which can be safely oxidized by the river.

FIGURE 3-1 (Alberta Department of Public Health) shows the dissolved oxygen level at various locations downstream from Edmonton for three grab samples in the month of October, before ice cover; and for the average of four December samples as previously plotted (FIGURE 1-1). FIGURE 3-1 indicates that in October the river reached critical conditions, approximately one day's time flow below Edmonton and recovered two days later. In December, under ice cover, the river could not recover due to no reaeration, and the dissolved oxygen level continued to decrease.

To determine how the added treatment affects the river, a composite sample of the North Saskatchewan River at Fort Saskatchewan (22 river miles downstream from Edmonton) was collected on the 16th of October 1965 before the secondary sewage treatment plant was in operation.

A second composite sample was taken on December 18, 1965, at Fort Saskatchewan. At this time the secondary sewage treatment had been in full operation for a period of 31 days. The microbial flora of the river should have stabilized within this period of time.

Comparison of the 20°C, deoxygenation rate constants, ultimate first-stage B.O.D., degree of nitrification, and the time which the

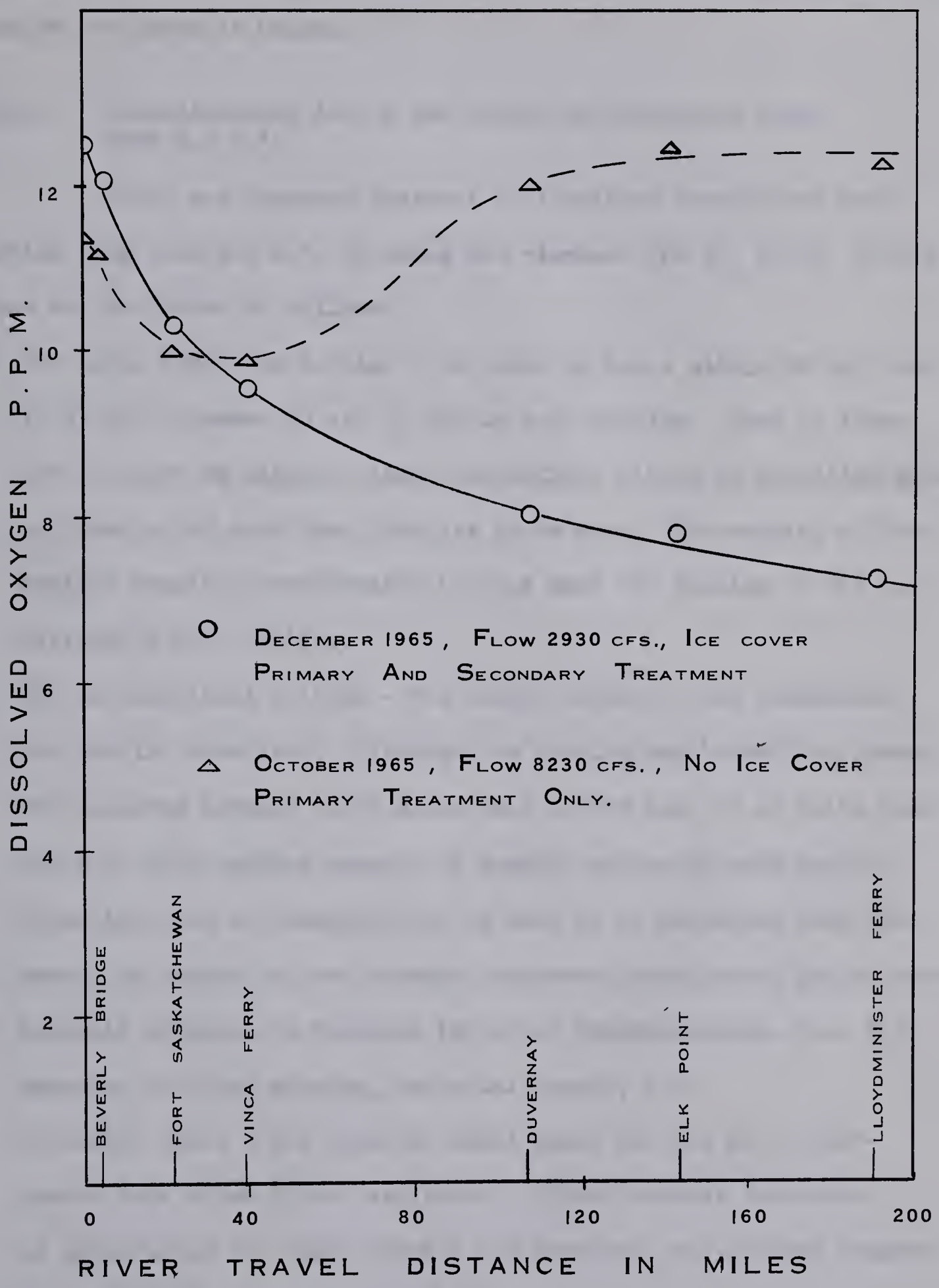


FIGURE: 3 - 1 EFFECT OF ICE COVER ON THE DISSOLVED OXYGEN CONTENT IN THE NORTH SASKATCHEWAN RIVER



products of nitrification commenced and disappeared for the two sets of samples are given in Chapter IV.

III-4 Investigations into a New Method of Conducting Long Term B.O.D.'s

There are numerous inherent difficulties encountered when running long term B.O.D.'s by using the standard 300 ml. B.O.D. bottle. These may be listed as follows:

a) The large number of bottles - In order to run a single 30 day test it is not uncommon to set up 100 or more bottles. Each of these bottles must be washed, rinsed, acidified, rinsed in distilled water and then dried each time they are to be used. The washing of the bottles requires considerable time as does the filling of the individual B.O.D. bottles.

b) Use of individual bottles - The sewage sample is not homogenous nor totally dissolved. Although the samples may be settled sewage, and filtered through fibre glass wool before use, it is quite possible to have varying amounts of organic matter in each bottle. Since the rate of deoxygenation is said to be dependent upon the amount of organic matter present, erroneous results can and do occur.

c) Separate bottles are required for other determinations, i.e. for ammonia, nitrite, nitrate, bacterial counts, etc.

d) Incubator space - The required shelf space for one set of determinations often is not available. Unless special incubators, as constructed for these studies are provided, any testing program is spread over a long period of time.

The use of the Jug Dilution Technique (Orford, Rand, Gellman,

1963) is one method which has been tried with fair success.

The method consists of filling two one-gallon jugs with the sample. One jug is completely filled and stoppered to prevent aeration; the other jug is left open to the atmosphere. For sampling the stopper is removed from the bottle and a sample syphoned off. After sampling, the jug from which the sample was taken is carefully filled (care being taken to minimize aeration) from the second jug. The first jug is then restoppered until the next sampling period.

Results obtained by the above method indicates close agreement with the standard B.O.D. bottle tests.

Use of a closed container would ensure no reaeration; provide a composite sample for dissolved oxygen, nitrification, bacterial and other studies; require little shelf space; and increase the accuracy of the test.

To be workable the container would have to be flexible, to enable displacement of the sample; and of low gas transmissibility, to prevent transfer of oxygen into the sample. These conditions suggest two kinds of containers. The first being a flexible bag and the second a cylinder with a moveable piston.

Mylar (Reference - DuPont Trade Name), a polyester film made from polyethylene terespthalate, was chosen as a material for the bags; Perspex (Reference - C.I.L. Trade Name), a polymethyl metrarylate, was used for the cylinder and piston arrangement. The use of these two methods and materials are discussed separately in the following paragraphs.

Mylar - Mylar is a strong, tough polyester film manufactured by DuPont of Canada, Montreal. Physical properties of Mylar, Type "A", are given in TABLE III-1 and it's chemical properties in TABLE III-2.

Bags, FIGURE 3-2, were constructed of 0.0005 inch and 0.010 inch sheeting which was sealed with a special heat sealable Mylar tape (.0015 inchs thick). The capacity of each bag was approximately 7 liters.

The bags were incubated in a constant temperature water bath which was covered to prevent possible algae growth in the bags. Standard B.O.D. bottles were used to check results of the bag tests. These were incubated in the same water bath as the bags to prevent any temperature effects on the resulting B.O.D.'s.

Cylinders - A section of nine inch perspex tubing (8.625 inches I.D.) 30 inches long was sealed at one end and a weighted perspex piston fitted into the open end - FIGURE 3-3. A "John Crane" teflon O-ring (8.125 inches I.D. x 8.625 inches O.D.) was used to provide an air tight seal between the piston and cylinder. Taps were installed in the piston and bottom of the cylinder to facilitate sampling and aeration of the sample as well as providing a means to eliminate the air from the cylinder after filling or aerating. (See Appendix C for construction details)

Properties of Perspex are given in TABLE III-3.

In order to check the usefulness of the cylinders, standard B.O.D.'s were set up with the cylinder and incubated in the same incubator. Before using the cylinder on an actual B.O.D. test, several

TABLE III-1

MYLAR TYPE "A"

PHYSICAL PROPERTIES*

Property	Typical Value (per mil.)
Ultimate Tensile Strength	25,000 p.s.i.
Yield Point	12,000 p.s.i. at 4%
Ultimate Elongation	120%
Tensile Modulus	550,000 p.s.i.
Impact Strength	6.0 kg.-cm/mil
Folding Endurance	14,000 cycles
Tear Strength - propagating	15 gm./mil
Tear Strength - initial (Graves)	600 gm./mil
Bursting Strength (Mullen)	1300 lbs./in.
Density	66 p.s.i.
	1.395

* Bulletin M-IC, Film Department, DuPont of Canada

TABLE III-2

MYLAR TYPE "A"

CHEMICAL PROPERTIES*

Property	Typical Value		
Chemical Resistance	Percent Tensile Strength Retained	Percent Elongation Retained	Percent Tear Strength Retained
to acetic acid, glacial	Resident	100	100
to hydrochloric acid-10%	Resident	100	100
to sodium hydroxide-2%	Resident	100	70
to ammonium hydroxide-conc.	Not Resident	0	0
to trichloroethylene	Resident	100	100
to hydrocarbon oil	Fairly Resident	88	87
to phenolic resin,GE1678	Fairly Resident	3	73
Moisture Absorption	Less than 0.8%		

Permeability	cc/(100 sq.in.) (24 hrs.) (atm./mil)
Gas	
Carbon Dioxide	16
Hydrogen	100
Nitrogen	1
Oxygen	6
Vapors	grams (100 sq.in.) (24 hrs.) (atm./mil)**
Acetone	2.22
Benzene	0.36
Carbon Tetrachloride	0.08
Ethyl Acetate	0.08
Hexane	0.12
Water	1.80
Fungus Resistance	Inert
Copper Corrosion	Neglible

* Bulletin M-IC, Film Department, DuPont of Canada

** Vapor permeabilities are determined at the partial pressure of the vapor at the temperature of the test

0.0005 INCH
MYLAR



0.010 INCH
MYLAR

FIGURE 3 - 2 MYLAR BAGS



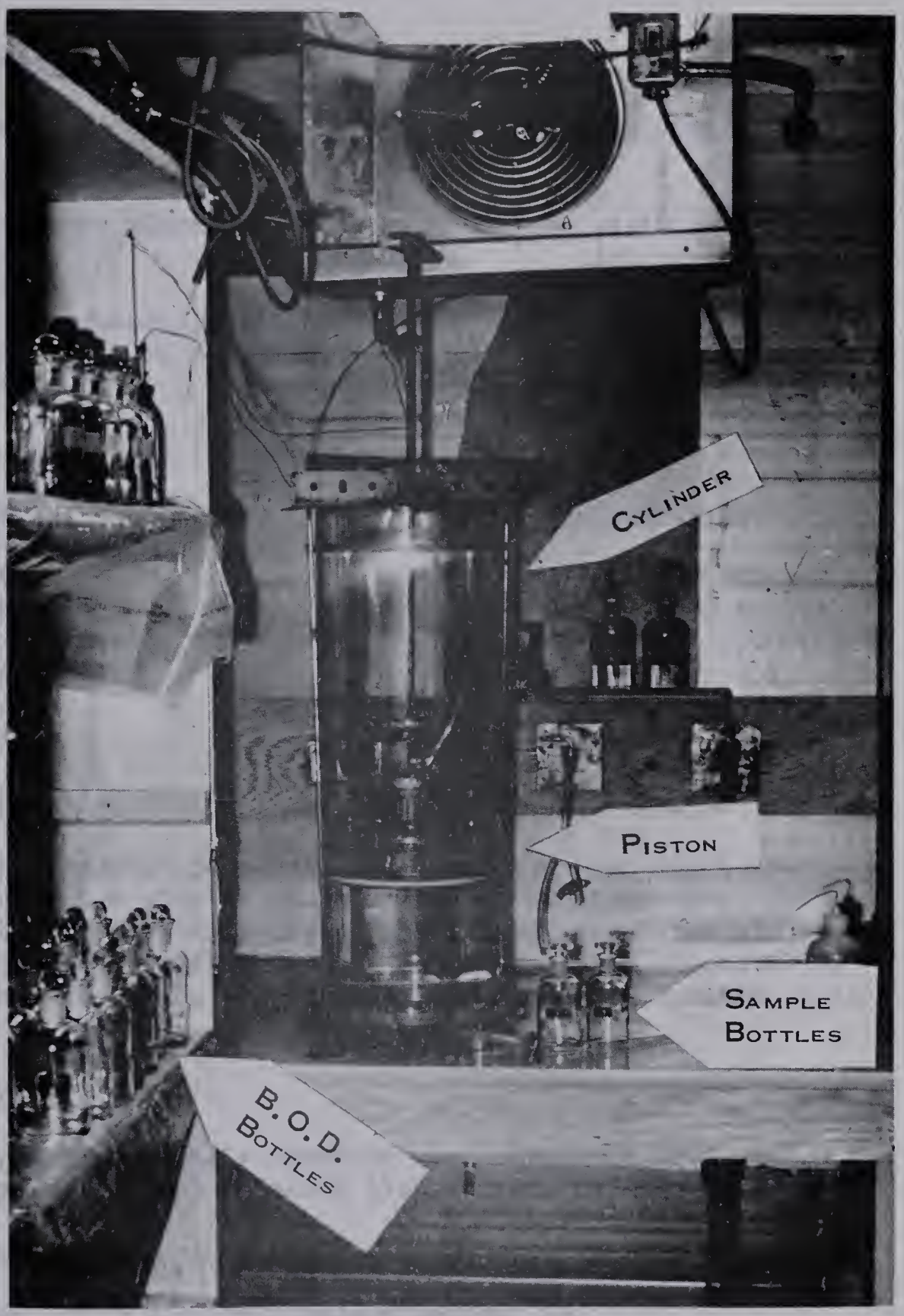


FIGURE 3 - 3 PERSPEX CYLINDER



TABLE III-3

PROPERTIES OF PERSPEX*

a) Physical Properties

Property	Typical Value
Specific gravity at 20°C	1.19
Effect of exposure to ultra violet light	No visible effect in 480 hours
Water absorption	0.3 - 0.4%
Swelling after immersion in water (increase in length of specimen)	0.04 - 0.10%
Resistance to burning	Burns very slowly

b) Mechanical Properties (at 20°C)

Property	Typical Value
Tensile strength	8,500 - 10,000 p.s.i.
Impact strength	0.25 - 0.35 ft. lb.
Cross breaking strength	14,500 - 15,600 p.s.i.
Modulus of elasticity	4.5×10^5 p.s.i.
Shear strength	8,500 - 10,000 p.s.i.
Pyramid hardness	19 - 21

c) Optical Properties

Clear "Perspex" possesses outstandingly high light-transmission throughout the visible range. A sheet of clear "Perspex" transmits about 92% of visible light, the slight loss being almost entirely due to surface reflections. The transparency of sheets is unimpaired by heating or by long exposure to moisture or ultra violet light.

d) Chemical Properties

Perspex is generally inert to most chemicals encountered in the sanitary field. For detailed list consult reference.

e) Gas Permeability**

Oxygen - 0.043×10^{-10}/cm/cm^2/sec/cm. Hg
Helium - 7×10^{-10}/cm/cm^2/sec/cm. Hg
Carbon Dioxide - 0.033×10^{-10}/cm/cm^2/sec/cm. Hg

rates of diffusion at normal temperatures and pressure expressed as grams per centimeter

f) Resistance to Biological Activity - completely resistant

(C.I.L. Technical Bulletin)

several five day B.O.D. runs were made on the cylinder to determine if there was an oxygen demand created by the cylinder itself.

Five day B.O.D. tests, on sewage with chips of the various materials used in the cylinder added to the B.O.D. bottles, were conducted to determine if the materials used in the cylinder affected the B.O.D. Another series of tests, in which numerous small beads were added to the B.O.D. bottles, were conducted on sewage to determine if the presence of a larger surface area had any appreciable effect on the B.O.D. Results of these tests are given in the next chapter.

CHAPTER IV

ANALYSIS OF DATA

IV-1 Procedure and Method

Methods used and procedures followed in conducting the various tests using standard B.O.D. bottles, Mylar bags and the Perspex cylinder are provided in Appendix "A".

Appendix "A" also includes a brief outline for the construction and temperature control of the incubator; the variance in incubator temperature; information on the sample material used (including a complete analysis of the sewage); and the limitation of the study.

The tests were conducted in several separate series with various tests within the series being run at different temperatures and conditions (i.e. acidized samples, cylinder A). All tests conducted in any one series were set up using portions of the same sample.

Series number 2, 3, 4 and 6 were set up to determine the effect of temperatures and of acidizing a sewage sample. The standard 20°C tests (samples 2-6; 3-1; 4-1) and the 20°C "acidized" tests (samples 3-5; 4-2) were compared to tests conducted at 4°C (samples 3-2; 6-1) and to acidized test (sample 3-6) also at 4°C.

Series number 10, 12 and 14 were conducted on sewage at 20°C (samples 10-1; 12-1; 14-1); at 0°C (samples 10-2; 12-5); at 2°C (samples 10-3; 12-6); and at 5°C (sample 12-7). Tests were also conducted at 20°C using cylinder A (samples 12-2; 14-2).

North Saskatchewan River water samples from below Edmonton were set up (at 20°C) before Edmonton's secondary sewage plant was in operation (sample 9-1) and after it had been in operation (sample 13-1). Cylinder A (sample 9-2) was also used. In order to determine the B.O.D. curve constants at 0°C a sample (19-1) was obtained through the ice and incubated at 0°C.

IV-2 First Stage B.O.D. Curve Constants

The first stage B.O.D. constants are given by the deoxygenation constant "k" and the ultimate first stage B.O.D. "L" and have been computed using the Thomas method (Thomas 1950). FIGURE 4-1 illustrates a plot used in the Thomas method for determining "k" and "L" for data given in TABLE IV-1. FIGURE 4-2 and 3 show the same data plotted on arithmetic and semi-log paper.

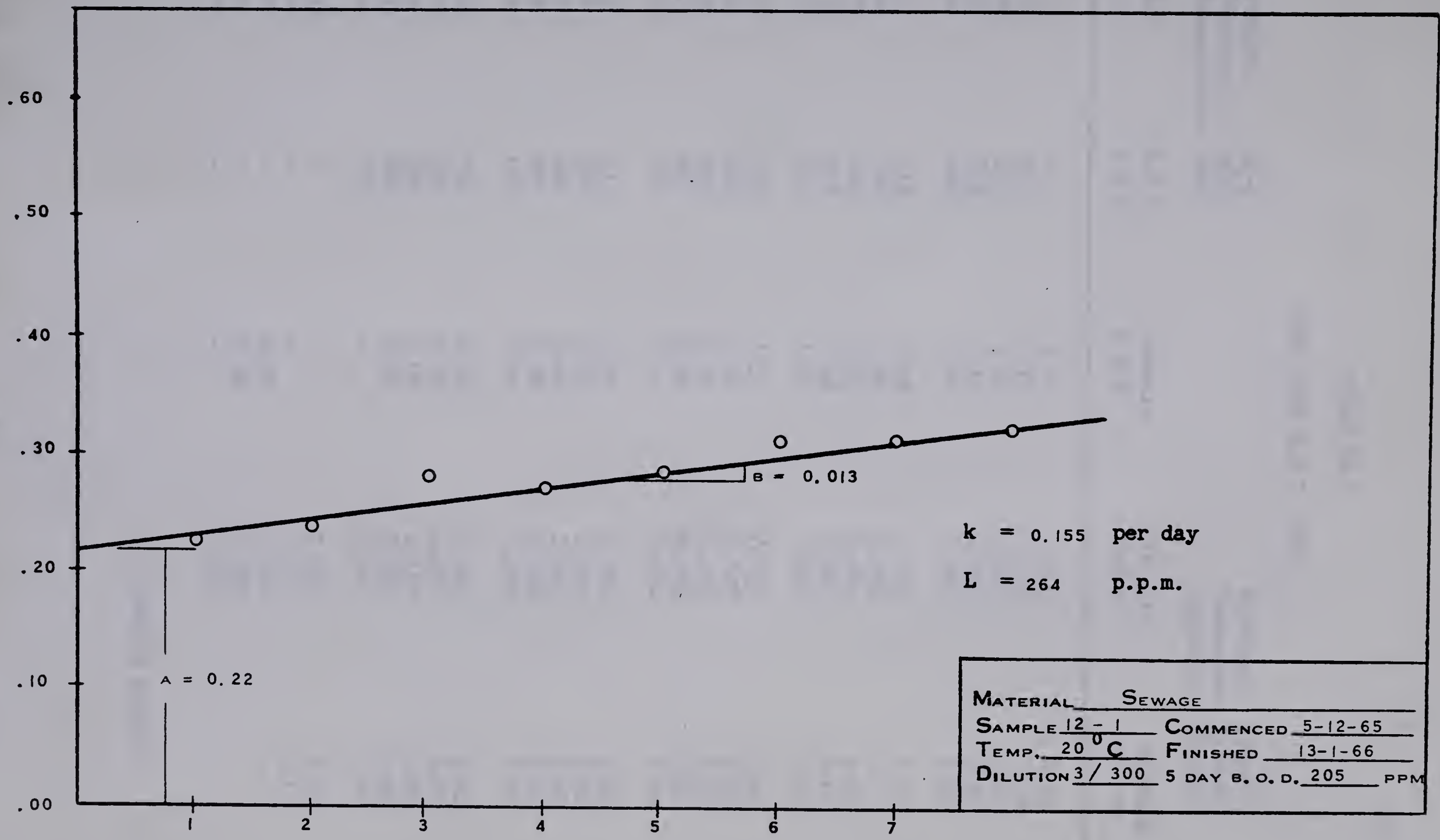


FIGURE: 4 - 1 B. O. D. CURVE CONSTANTS

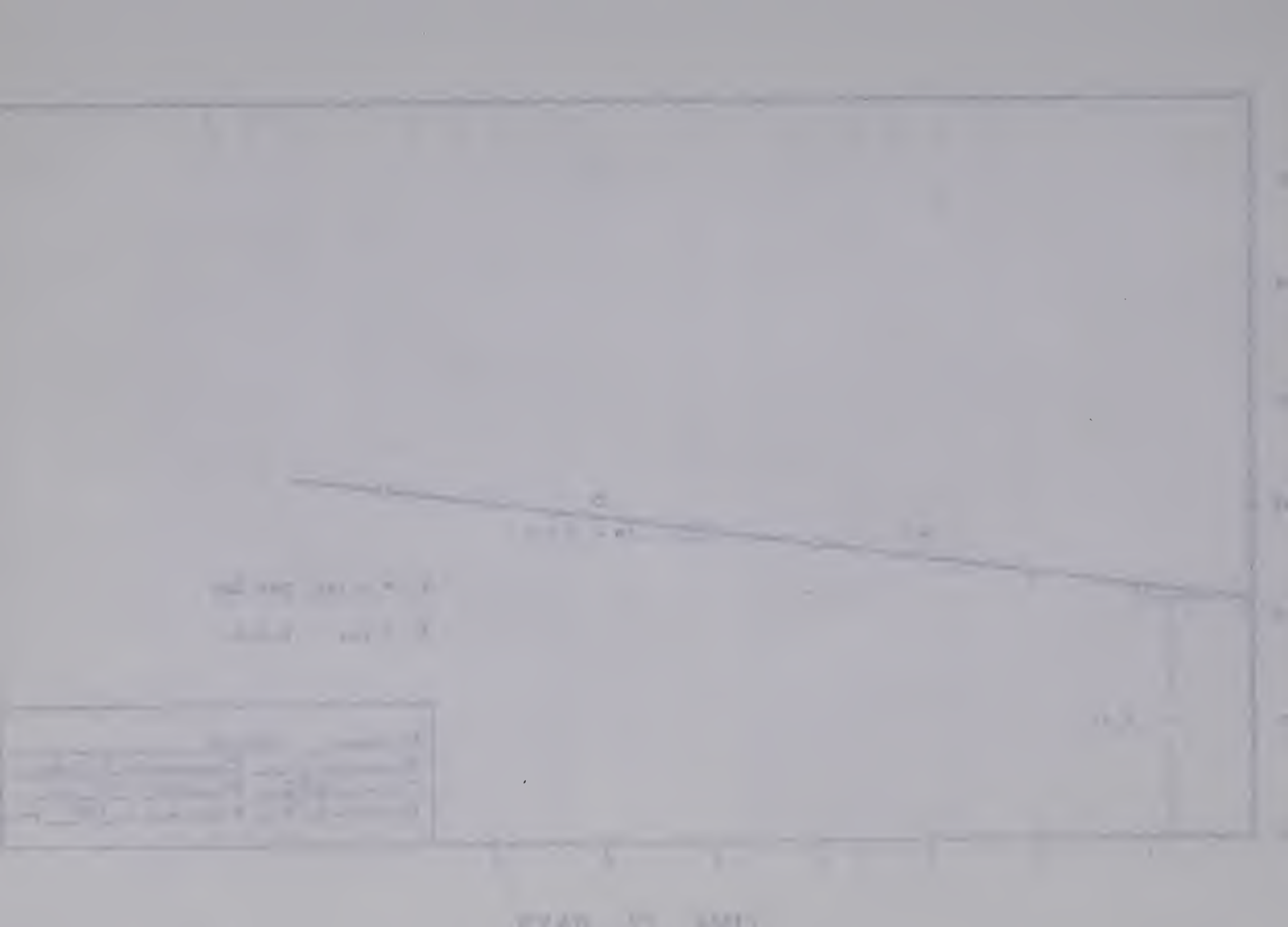


TABLE IV-1

LONG TERM B.O.D. DATA

Sample: 12-1 Material: Sewage
Dilution: 3/300 Commenced: 5/12/65
Temperature: 20°C Finished: 13/1/66

Day	B.O.D. p.p.m.	Ammonia p.p.m.	Nitrite p.p.m.	Nitrate p.p.m.
0	-	1.32	0.002	0.50
1	85	1.17	0.002	0.00
2	145	1.20	0.002	0.10
3	135	1.19	0.003	0.05
4	200	1.18	0.003	0.05
5	215	1.28	0.002	1.30
6	190	1.22	0.003	-
7	220	1.22	0.004	0.00
8	227	1.18	0.009	0.00
9	215	1.18	0.020	0.15
10	250	1.12	0.052	0.00
11	260	1.04	0.107	0.20
12	302	1.06	0.280	0.00
13	487	0.82	0.360	0.15
14	570	0.14	1.040	0.00
15	635	0.06	1.080	0.00
16	630	0.12	1.050	0.00
17	662	0.00	1.080	0.00
18	695	0.00	1.040	0.34
19	627	0.00	1.150	0.00
20	715	0.00	1.180	0.00
21	698	0.06	1.050	0.00
22	738	0.06	1.100	0.00
23	778	0.00	1.075	0.00
24	793	-	1.100	0.00
25	-	-	1.050	0.05
26	-	-	1.130	0.17
27	-	0.00	1.080	-
28	-	0.00	1.080	-
29	-	-	1.000	-

.....cont'd page 44

TABLE IV-1 continued from page 43

Day	B.O.D. p.p.m.	Ammonia p.p.m.	Nitrite p.p.m.	Nitrate p.p.m.
30	1025	-	1.050	0.00
31	-	-	0.880	-
32	-	-	0.910	-
33	-	-	0.860	-
34	-	-	0.790	0.37
35	-	-	0.590	-
36	-	-	0.410	-
37	-	-	0.150	-
38	-	-	0.002	0.88
39	1158	-	0.001	0.46

See FIGURES 4-1, 2, 3, 55

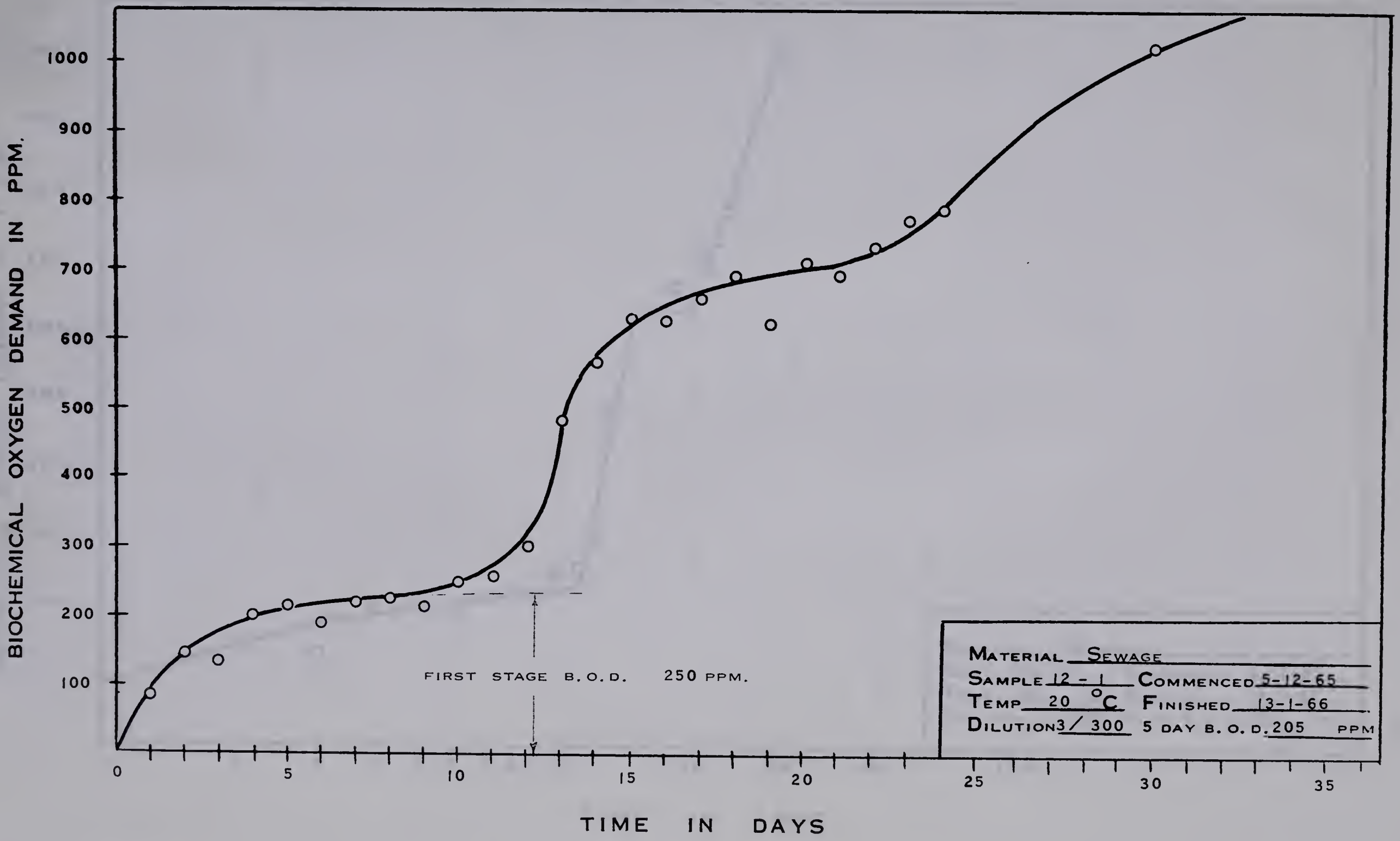
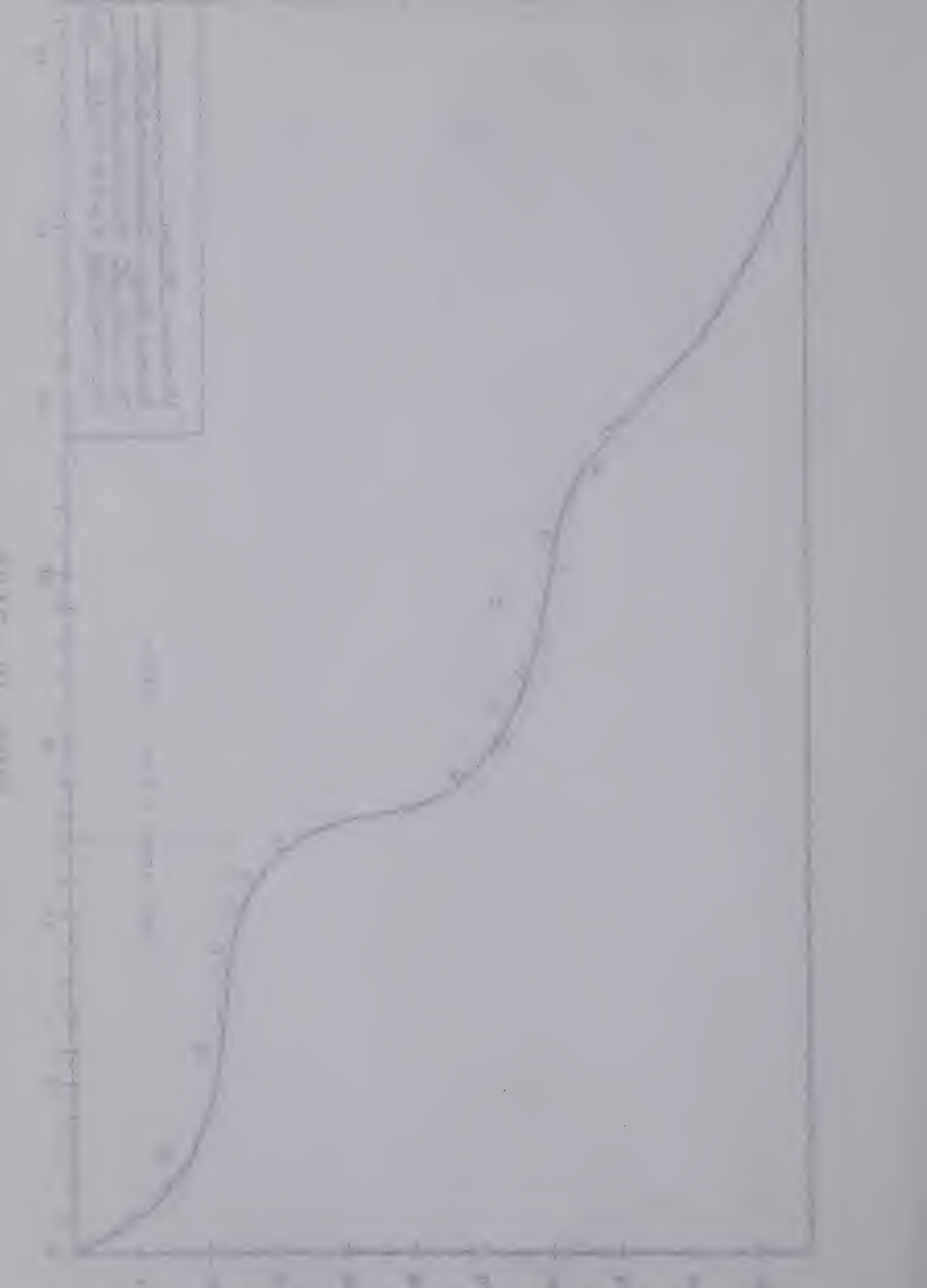


FIGURE: 4 - 2 NORMAL B.O.D. CURVE " ARITHMETIC PLOT"



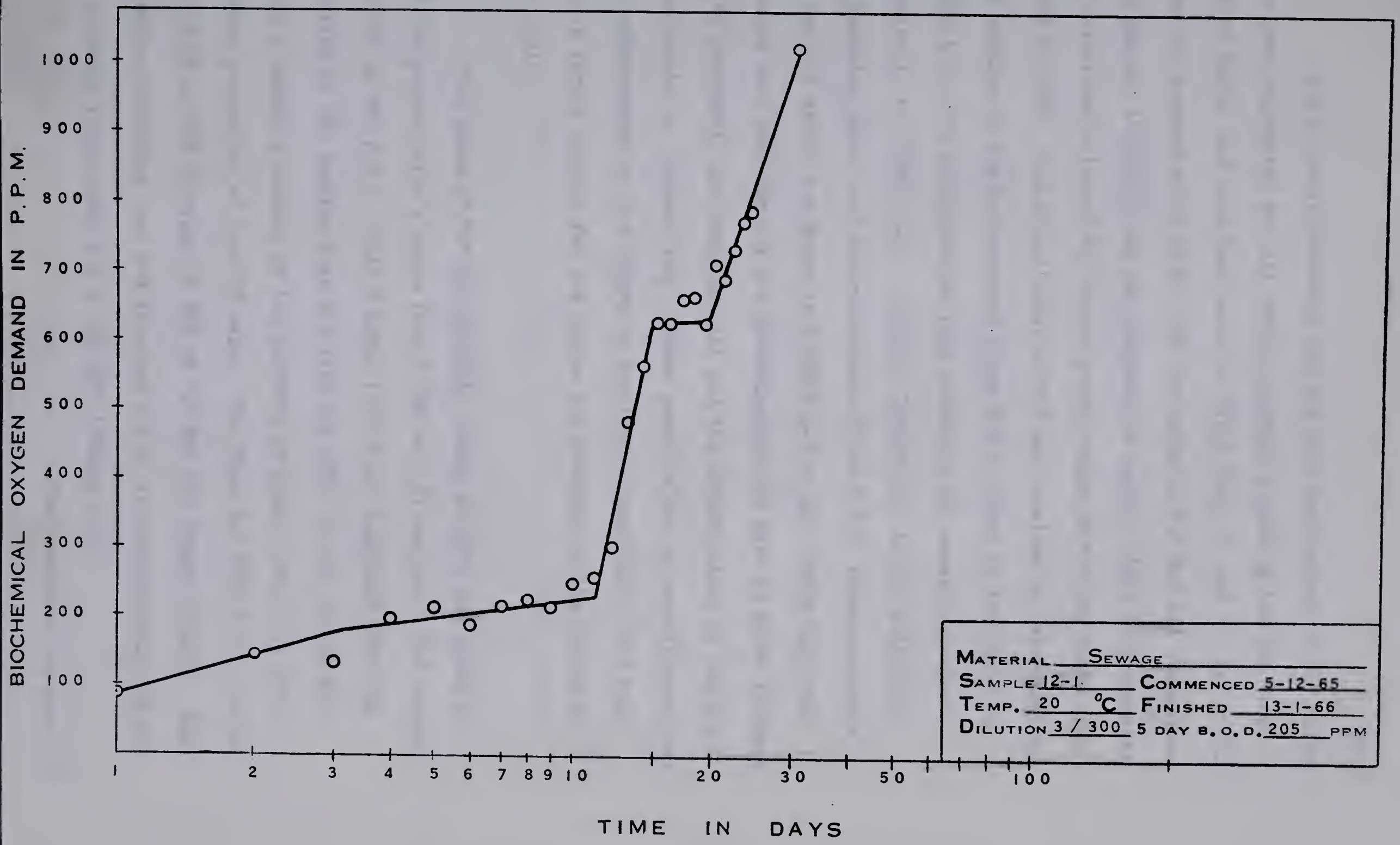


FIGURE: 4—3 B. O. D. CURVE "SEMI - LOG"



B.O.D. curve constants and the five day percent of "L" values have been calculated for all samples tested, including the low temperature tests. and have been shown in TABLE IV-2, 3, and 4. TABLE IV-5 gives the average value of "k" and the range of "L" for all sewage samples tested including the low temperature tests. TABLE IV-6 compares the calculated value of "L" to the actual value of "L" for tests conducted at 20°C. The actual value of "L" was obtained by extending the last portion of the carbonaceous stage B.O.D. curve as indicated on FIGURE 4-2. The deoxygenation rate constants for sewage are shown graphically in FIGURE 4-4. All data, TABLES IV-7 to 27; arithmetic and semi-log plots; and determinations of the B.O.D. curve constants. "k" and "L" plots are given in FIGURES 4-5 to 48. These have been arranged such that for any one determination the data is given followed by the arithmetic and semi-log plot and the determination of the B.O.D. curve constants respectively. Where possible one or more figures have been superimposed on the figure to facilitate comparison. The respective figure numbers for the tables are provided at the bottom of each table

The value of "k" for domestic sewage at 20°C was found to be 0.139 per day with a range from 0.098 to 0.17 per day. "L" varied from 135 to 290 p.p.m. Fair & Geyer (1965) has suggested that the variation of "k" implies that the five day 20°C, B.O.D. is not by itself a complete measure of the strength of sewage, as it is not a constant proportion of the "L" value. The five day 20°C B.O.D. varied from 68.1% to 88% (average 79.9%) of "L" for six sewage samples. Most literature indicates that the five day B.O.D. is approximately 68% of the ultimate first stage B.O.D. at 20°C (Phelps 1948).

Text continued on page 122

TABLE IV-2

B.O.D. CURVE CONSTANT

20°C SEWAGE

Table Number	Sample* Number	k per day	L p.p.m.	5 day % of L
Standard Test				
IV-7	2-6	0.105	215	81.5
IV-8	3-1	0.098	135	68.1
IV-12	4-1	0.145	152	77.6
IV-17	10-1	0.170	210	86.6
IV-1	12-1	0.155	264	77.5
IV-25	14-1	0.162	290	88.0
Acidized Test				
IV-10	3-5	0.228	138	85.5
IV-13	4-2	0.124	112	64.4
Cylinder "A"				
IV-20	12-2	0.137	343	83.4
IV-26	14-2	0.057	825	47.8

* Sample 3-1 - indicates the 1st test in the 3rd series of test.

All tests in one series were conducted on portions of the same sewage sample.

TABLE IV-3

B.O.D. CURVE CONSTANTS

0°C to 5°C, SEWAGE

Temp. °C	Table Number	Sample** Number	k per day	L p.p.m.	Lag Days	B.O.D. p.p.m.	Test
5	IV-23	12-7	0.096	66	1.5	15	Standard
4	IV-9	3-2	0.096	83	9.0	110	Standard
4	IV-14	6-1	0.079	52	2.0	50	Standard
4	IV-11	3-6	0.214	191	1.5	9	Acidized
2	IV-19	10-3	0.065	143	4.2	16	Standard
2	IV-22	12-6	0.059	63	2.5	10	Standard
0	IV-18	10-2	0.018	300	6.0	12	Standard
0	IV-21	12-5	0.067	59	3.0	10	Standard

** Sample 12-7 - indicates the 7th test in the 12th series of tests. All tests in one series were conducted on portions of the same sewage sample.

TABLE IV-4

B.O.D. CURVE CONSTANTS FOR

NORTH SASKATCHEWAN RIVER WATER

Temp. °C	Table Number	Sample Number	"k" per day	Calculated "L" p.p.m.	Actual "L" p.p.m.	River Flows c.f.s.	B.O.D. ***	Test
20	IV-15*	9-1	0.129	4.79	4.0	8.230	213,000	Standard
20	IV-16*	9-2	0.094	4.91	4.0	8,230	219,000	Cylinder A
20	IV-24**	13-1	0.121	2.39	1.8	2,600	34,600	Standard
0	IV-27**	19-1	0.178	1.22	1.2	3,120	20,500	Standard !

* Before secondary sewage treatment commenced at Edmonton (see sample)

** After secondary sewage treatment commenced at Edmonton

*** Pounds of B.O.D. per day (based on calculated "L") used by river

! Bottles filled in river and incubated at 0°C

TABLE IV-5

EFFECT OF TEMPERATURE ON

B.O.D. CURVE CONSTANTS OF SEWAGE

Temp. °C	Average of	k per day	Range of k per day	Range of L p.p.m.
Standard Test				
20	6	0.139	0.098-0.170	135-290
5	1	0.096	0.096	66
4	2	0.088	0.079-0.096	56-83
2	2	0.062	0.059-0.065	73-143
0	2	0.043	0.018-0.067	59-300
Acid Test				
20	2	0.176	0.124-0.278	112-138
4	1	0.214	0.124	191
Cylinder Test				
20	2	0.097	0.057-0.137	343-825

TABLE IV-6

COMPARISON OF THE CALCULATED FIRST STAGE B.O.D.

TO THAT OBTAINED FROM THE PLOTTED DATA

FOR 20°C SEWAGE SAMPLES

Sample Number	Calculated Value of "L" p.p.m.	Plotted Data Value of "L" p.p.m.
2-6	215	180
3-1	135	120
3-5	138	145
4-1	152	175
4-2	112	140
10-1	210	280
12-1	264	250
14-1	290	400
14-2	825	920

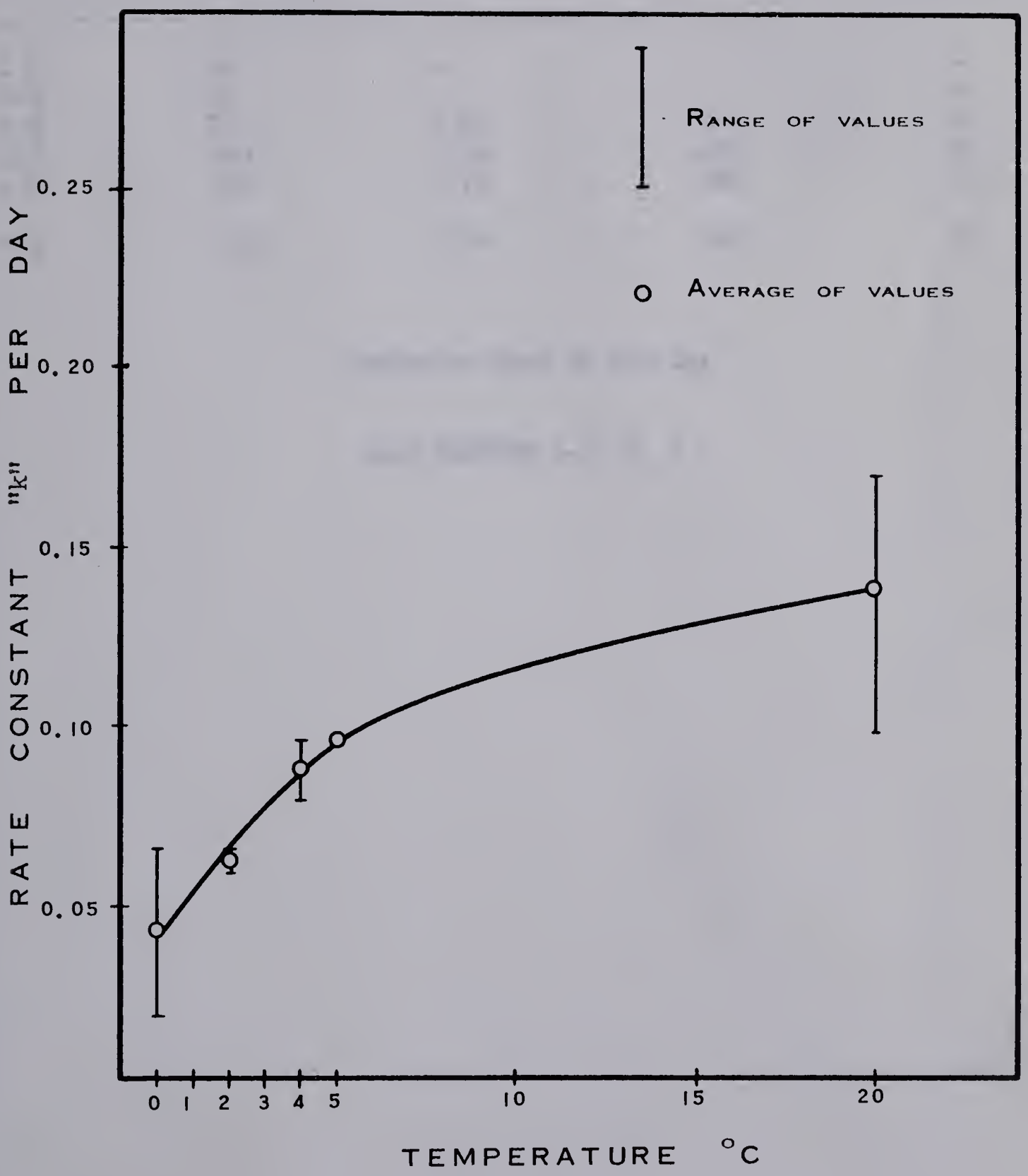


FIGURE 4 - 4 DEOXYGENATION RATE CONSTANTS



TABLE IV-7

LONG TERM B.O.D. DATA

Sample: 2-6
Dilution: 6/300
Temperature: 20°C

Material: Sewage
Commenced: 28/5/65
Finished: 2/6/65

Day	B.O.D. p.p.m.	Ammonia p.p.m.	Nitrite p.p.m.	Nitrate p.p.m.
1.2	40	-	-	-
2.2	85	-	-	-
2.9	75	1.82	.004	.02
3.9	100	1.68	.003	.01
4.8	150	1.72	.003	.00
5.9	155	1.76	.002	.27

Incubator down on 6th day

See FIGURES 4-5, 6, 7

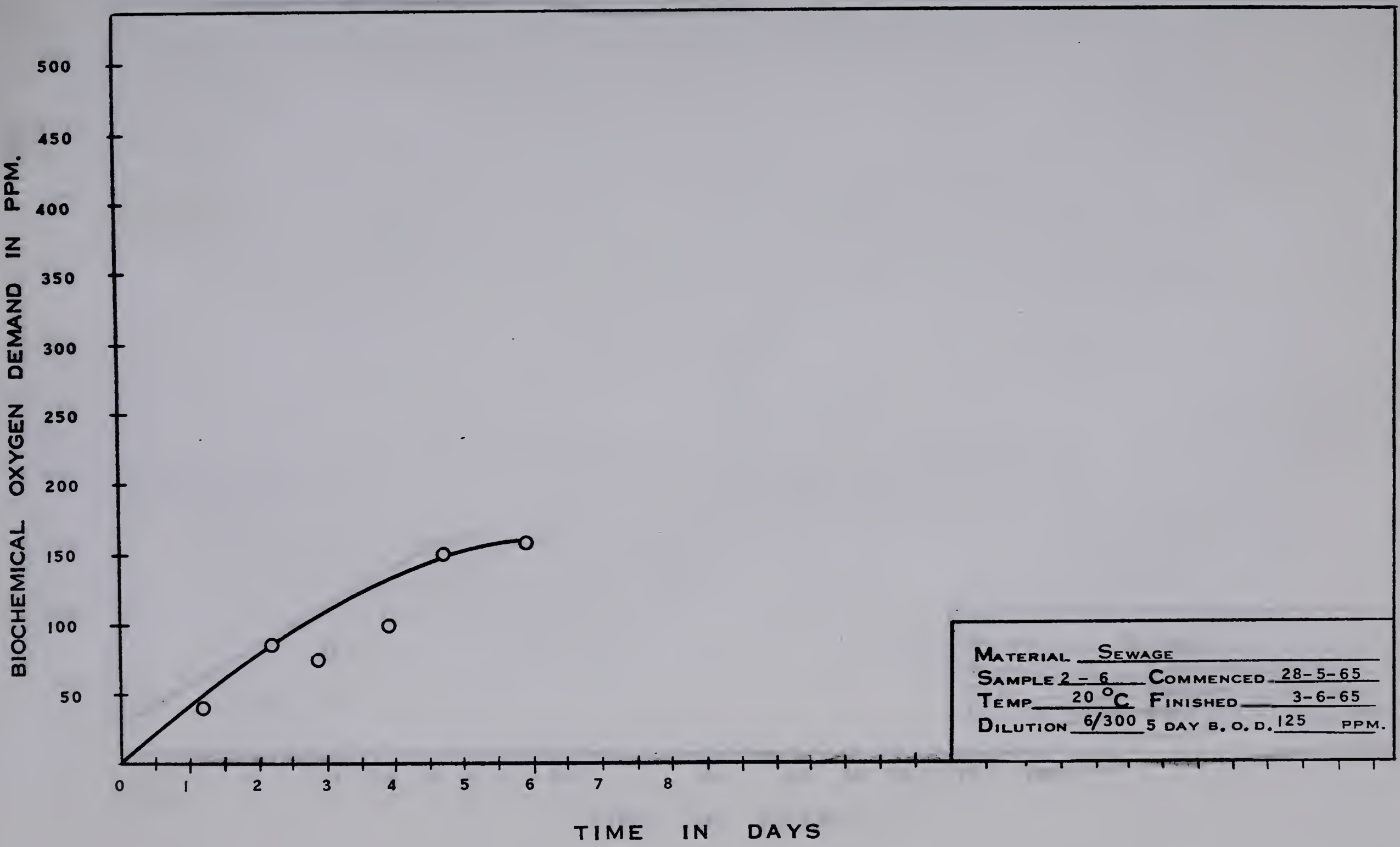
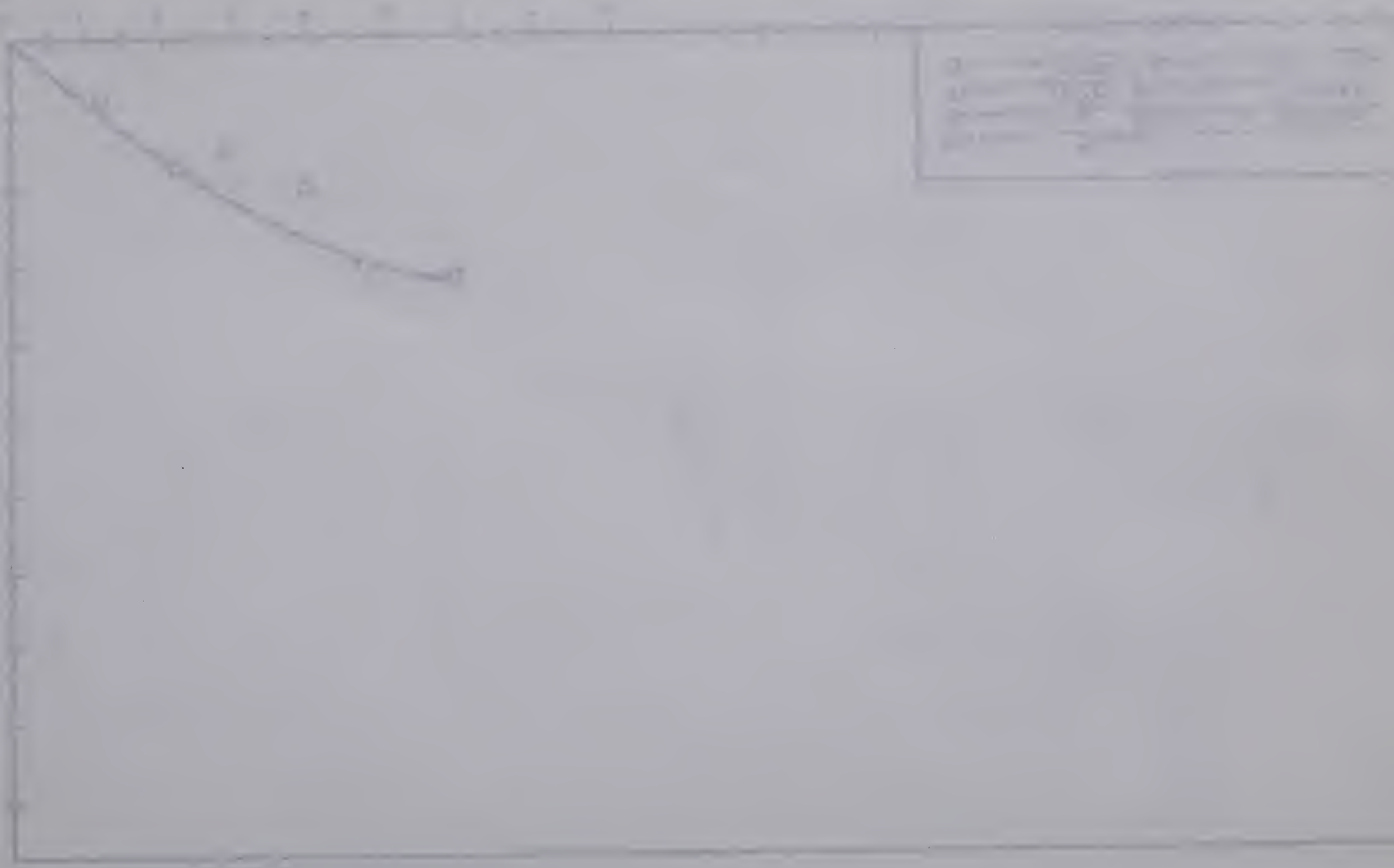


FIGURE: 4 - 5 NORMAL B. O. D. CURVE " ARITHMETIC PLOT "



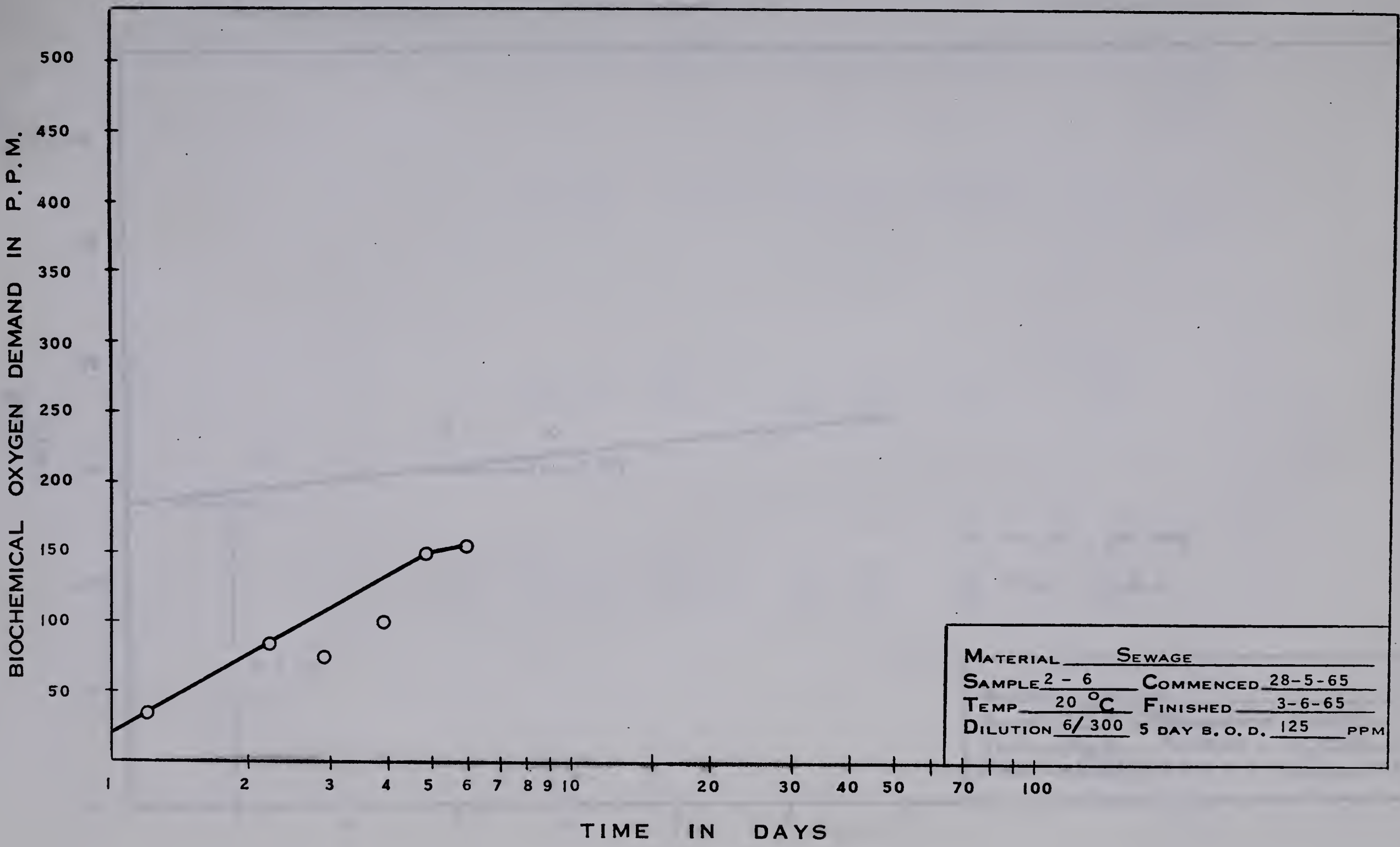
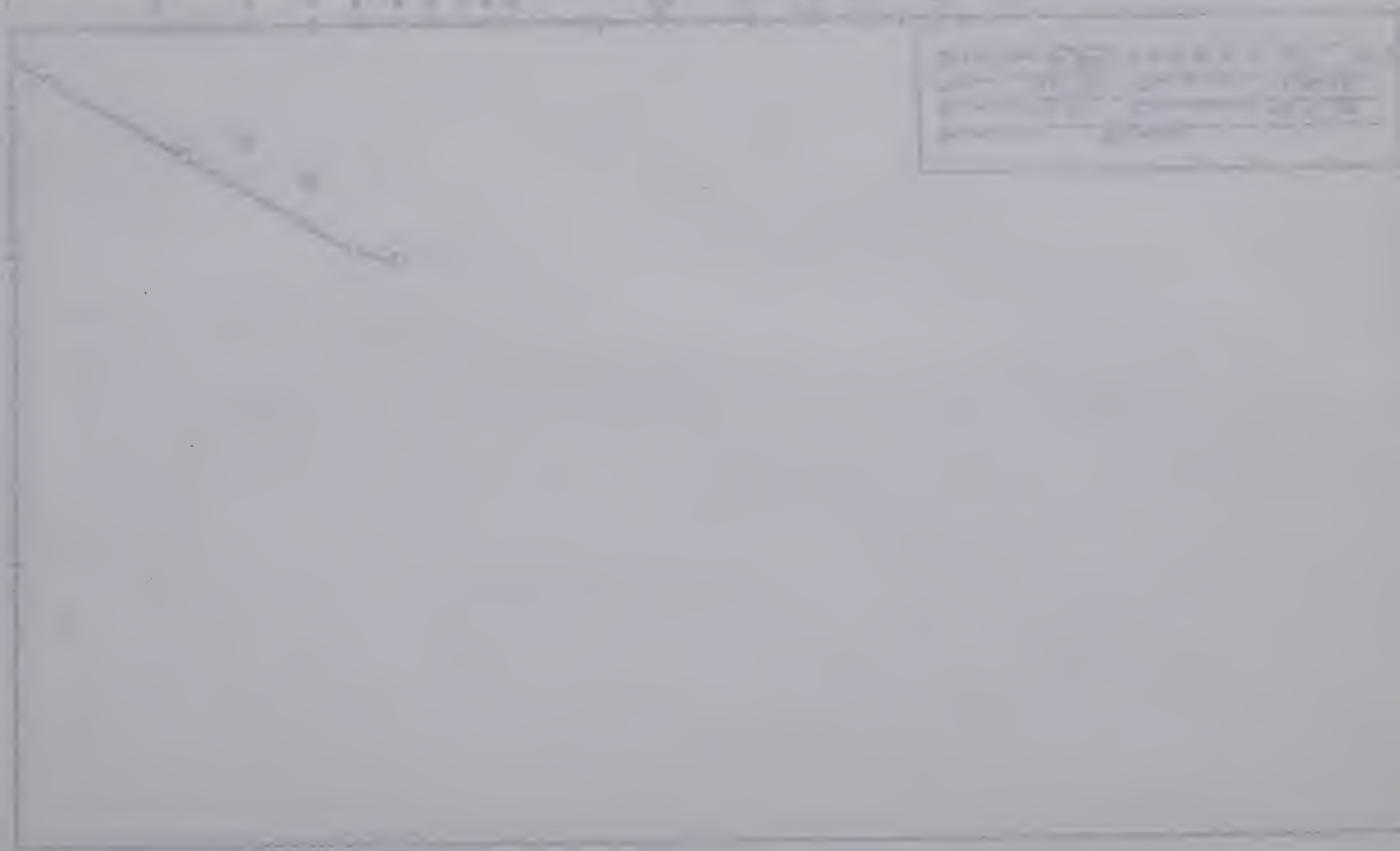


FIGURE: 4 - 6

B. O. D. CURVE "SEMI-LOG"



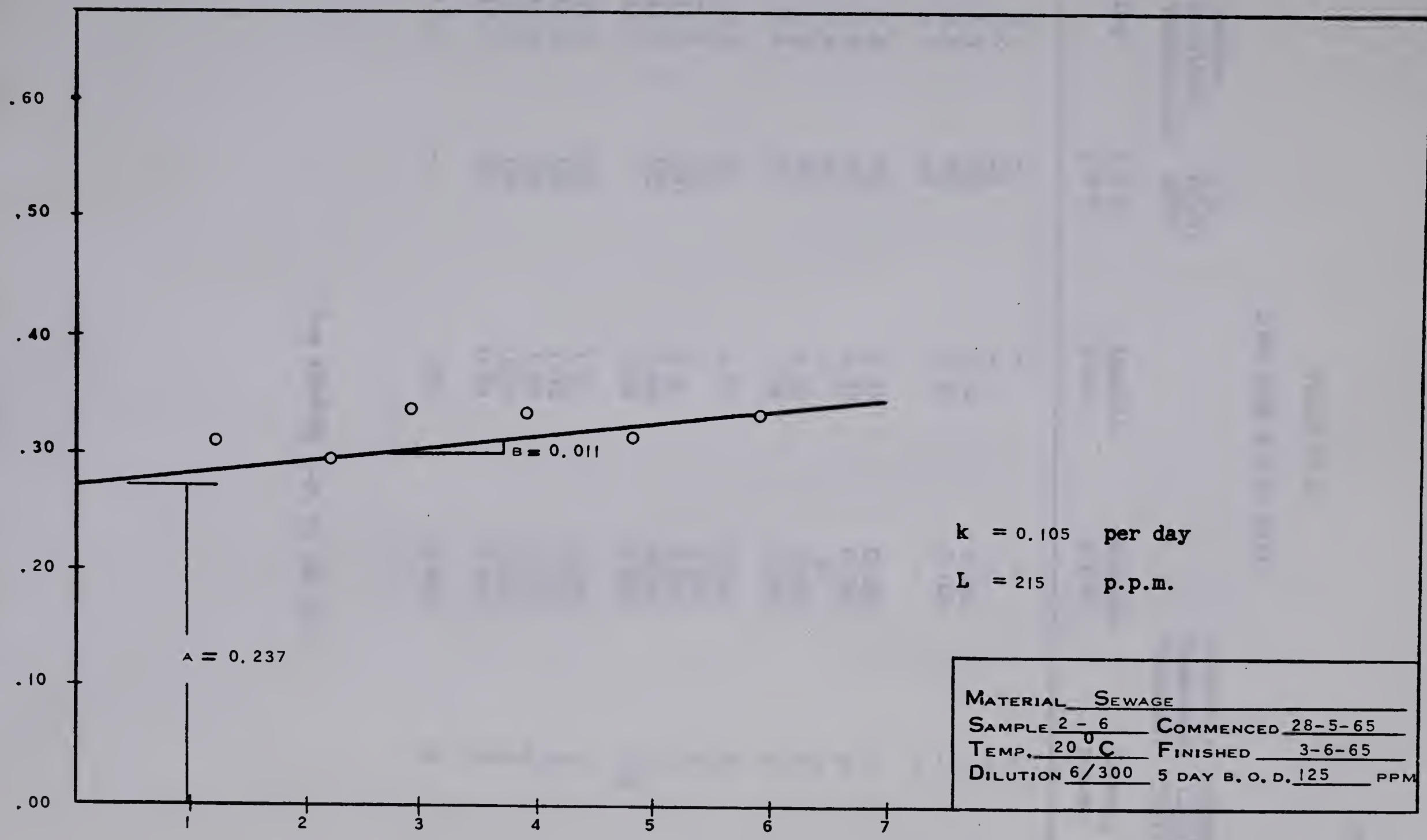


FIGURE: 4 - 7 B. O. D. CURVE CONSTANTS

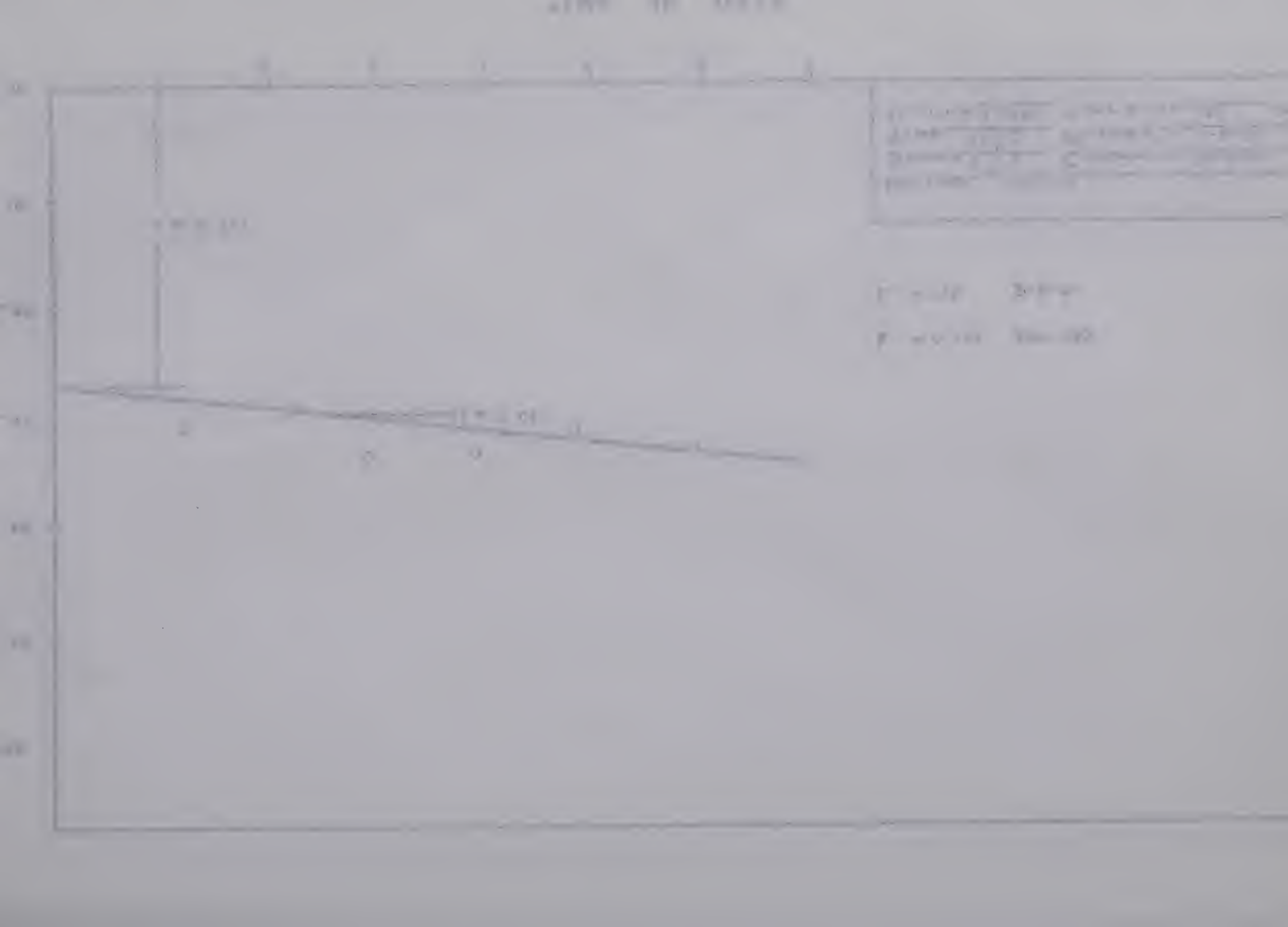


TABLE IV-8

LONG TERM B.O.D. DATA

Sample: 3-1
Dilution: 6/300
Temperature: 20°C

Material: Sewage
Commenced: 11/6/65
Finished: 30/7/65

Day	B.O.D. p.p.m.	Ammonia p.p.m.	Nitrite p.p.m.	Nitrate p.p.m.
0	-	-	-	-
0.9	15	-	-	-
1.9	70	1.52	0.002	-
2.8	63	1.52	0.001	-
3.0	60	-	-	-
3.8	78	1.52	0.002	-
4.8	90	1.52	0.005	0
5.8	95	-	-	-
6.8	88	1.62	0.004	0
8.1	95	1.68	0.006	-
9.7	93	1.76	0.021	0
10.7	124	-	0.006	-
11.7	150	1.24	0.280	0
12.7	133	1.62	0.150	-
13.0		1.68	0.140	.09
13.7	120	1.62	0.295	0
15.0	150	1.36	0.230	0
16.0	158	1.16	0.470	-
16.7	190	0.68	0.860	0
17.7	245	0.72	0.900	0
18.7	-	0.90	0.800	0

See FIGURES 4-8, 9, 10, 50

TABLE IV-10

LONG TERM B.O.D. DATA

Sample: 3-5
Dilution: 6/300
Temperature: 20°C

Material: Sewage (Acidized)
Commenced: 11/6/65
Finished: 30/6/65

Day	B.O.D. p.p.m.	Ammonia p.p.m.	Nitrite p.p.m.	Nitrate p.p.m.
0	-	-	-	-
0.9	65	1.56	.004	-
1.9	85	-	-	-
2.8	100	-	-	-
3.0	105	-	-	-
3.8	110	-	-	-
4.8	110	1.52	.005	-
5.8	125	1.39	.005	-
6.8	115	1.56	.005	-
8.1	120	1.58	.005	-
9.7	115	1.56	.004	-
10.7	135	-	-	-
11.7	125	1.52	.005	0
12.7	155	1.62	.005	-
13.7	135	1.56	.004	0
15.0	150	1.56	.005	0
16.0	145	1.52	.006	0
16.7	140	1.52	.006	0
17.7	165	1.52	.004	0
18.7	-	1.47	.004	0

See FIGURES 4-8, 9, 11, 51

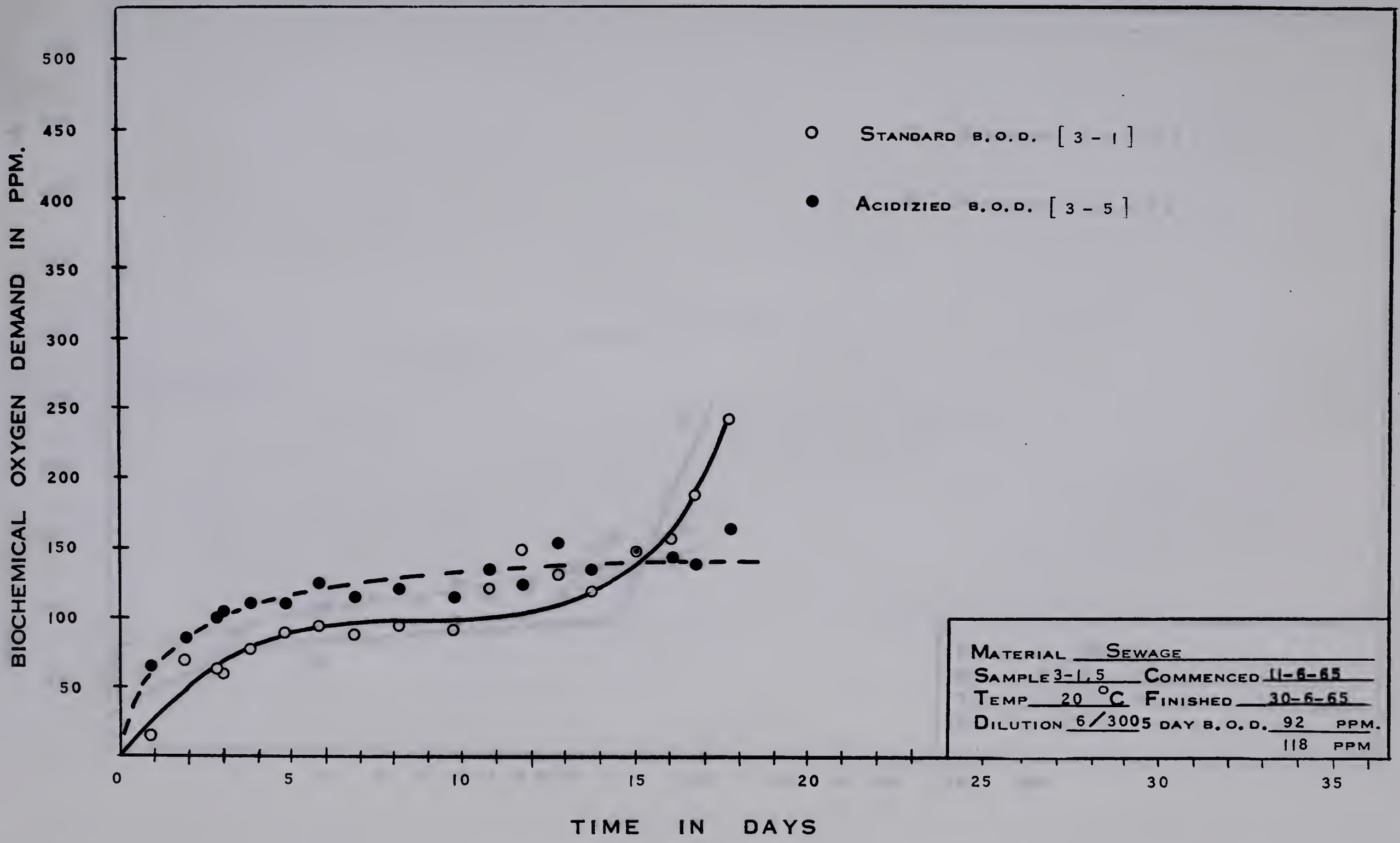
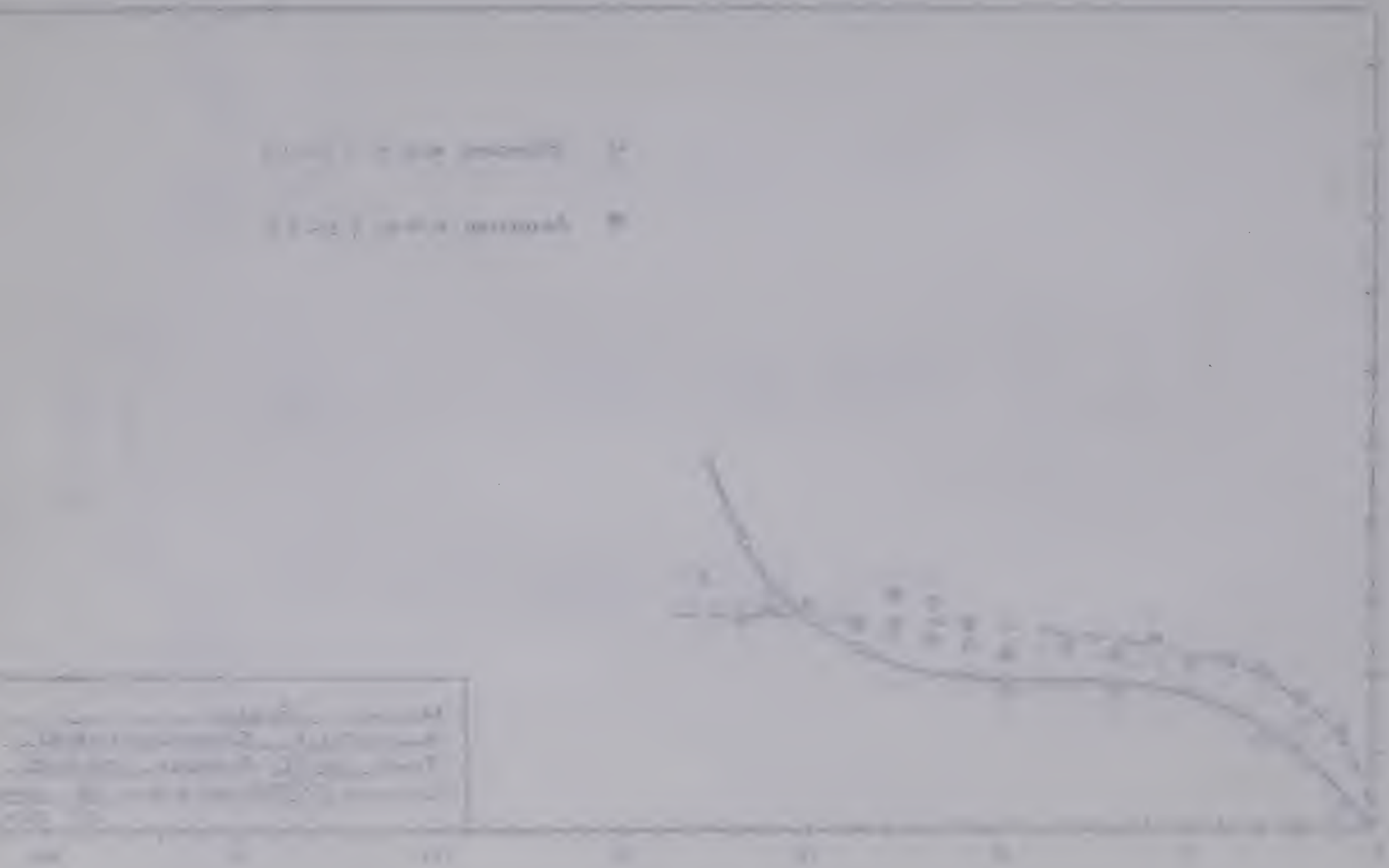


FIGURE: 4 - 8 NORMAL B. O. D. CURVE " ARITHMETIC PLOT "



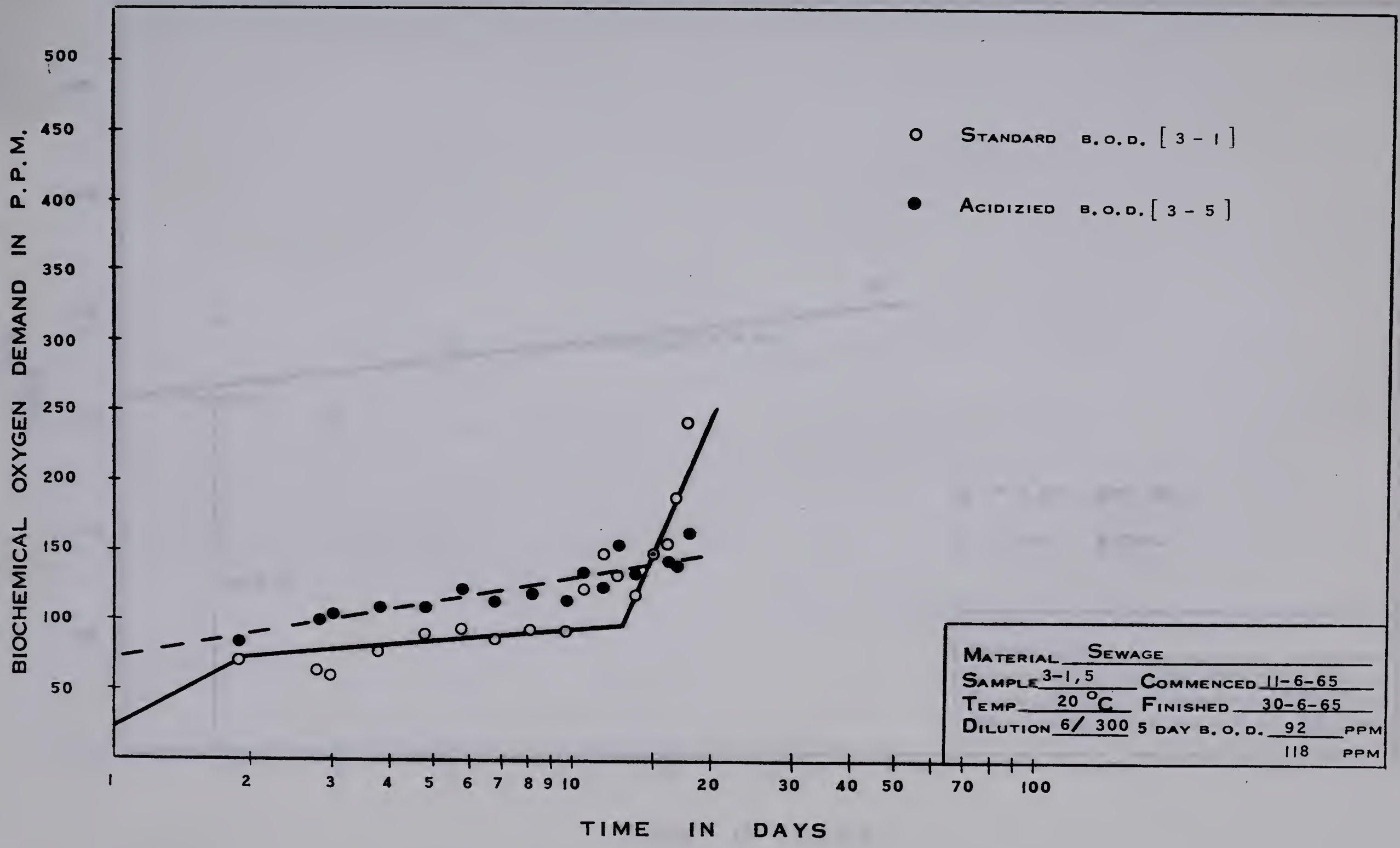
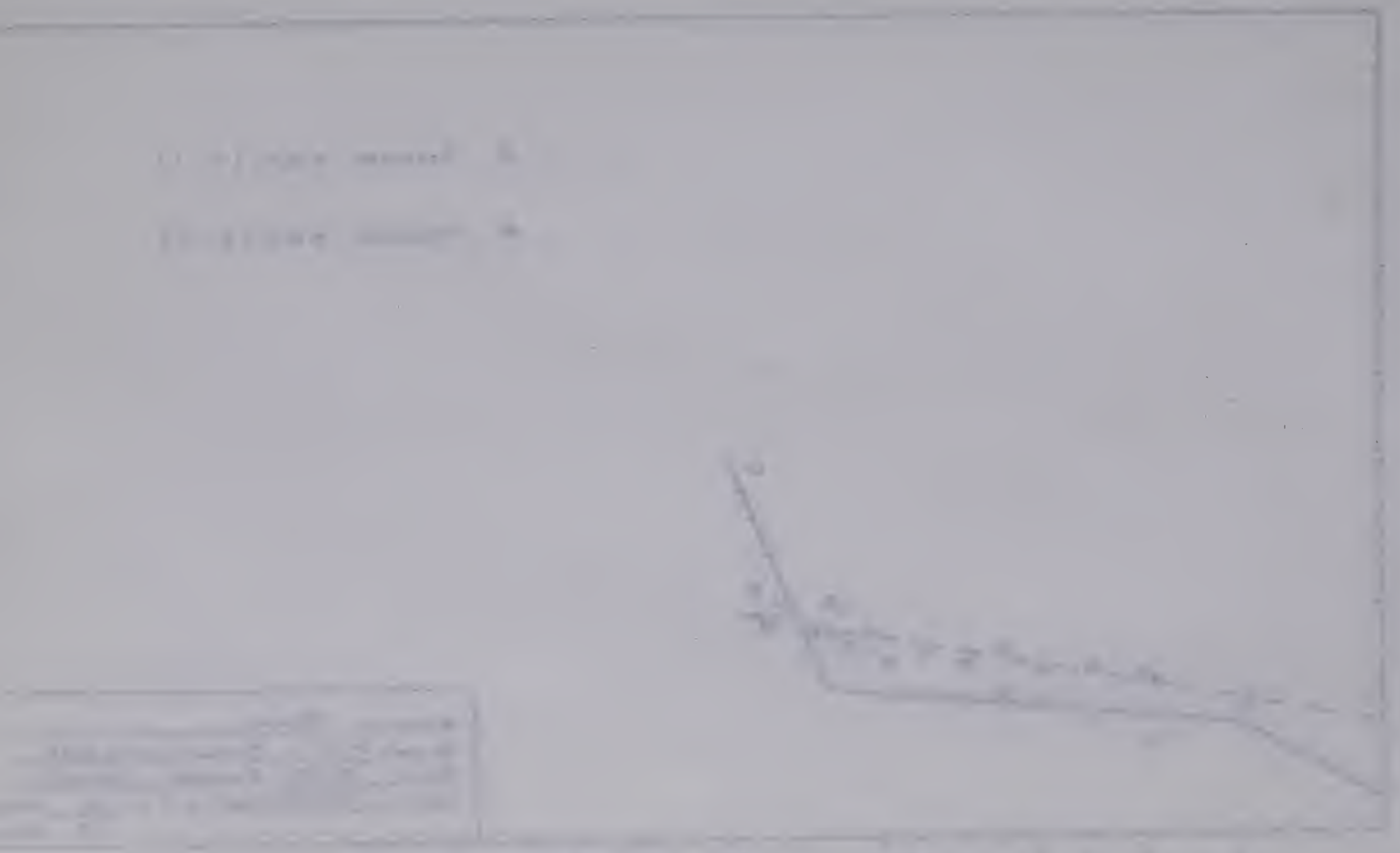


FIGURE: 4 - 9

B.O.D. CURVE "SEMI-LOG"



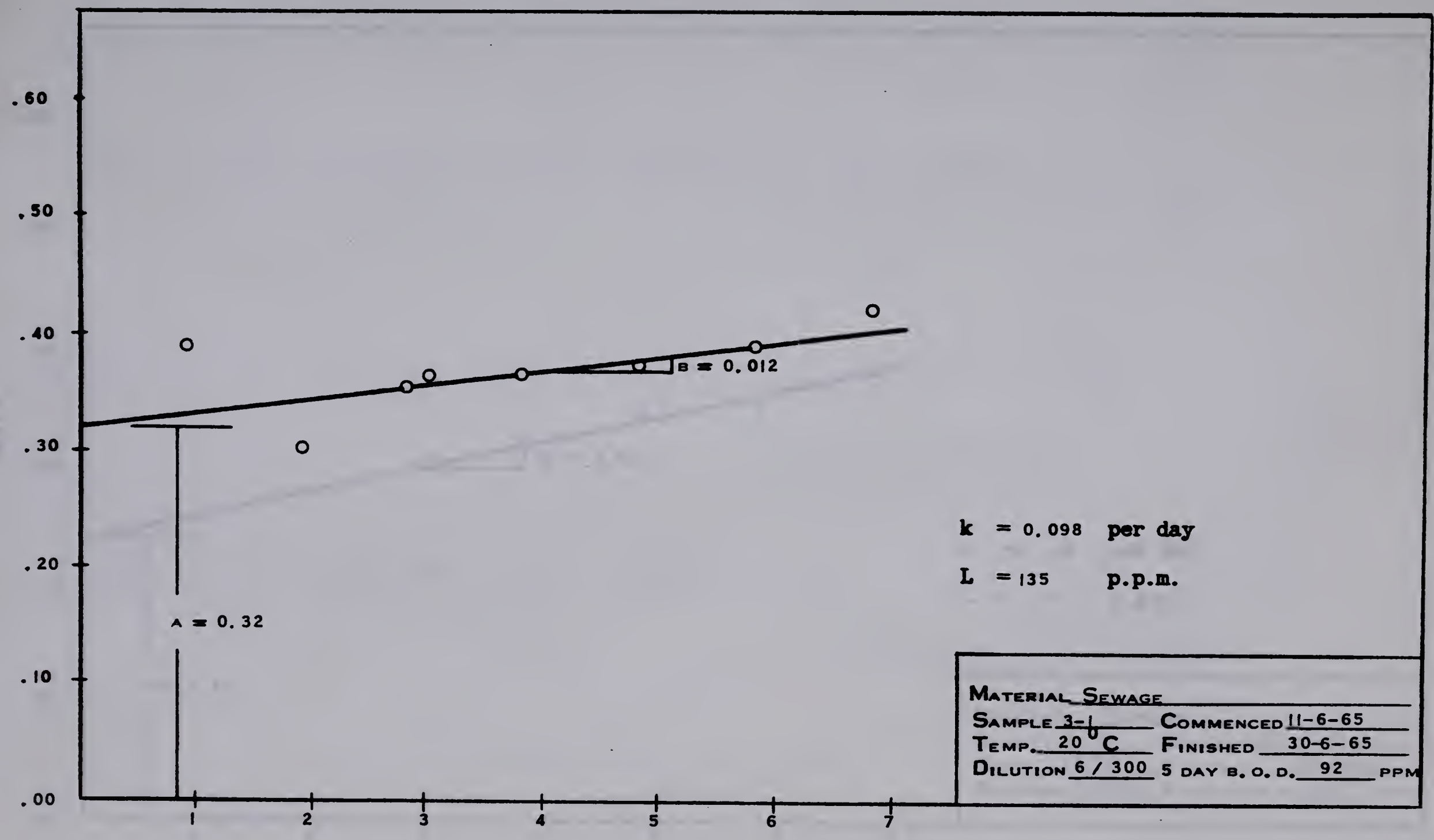
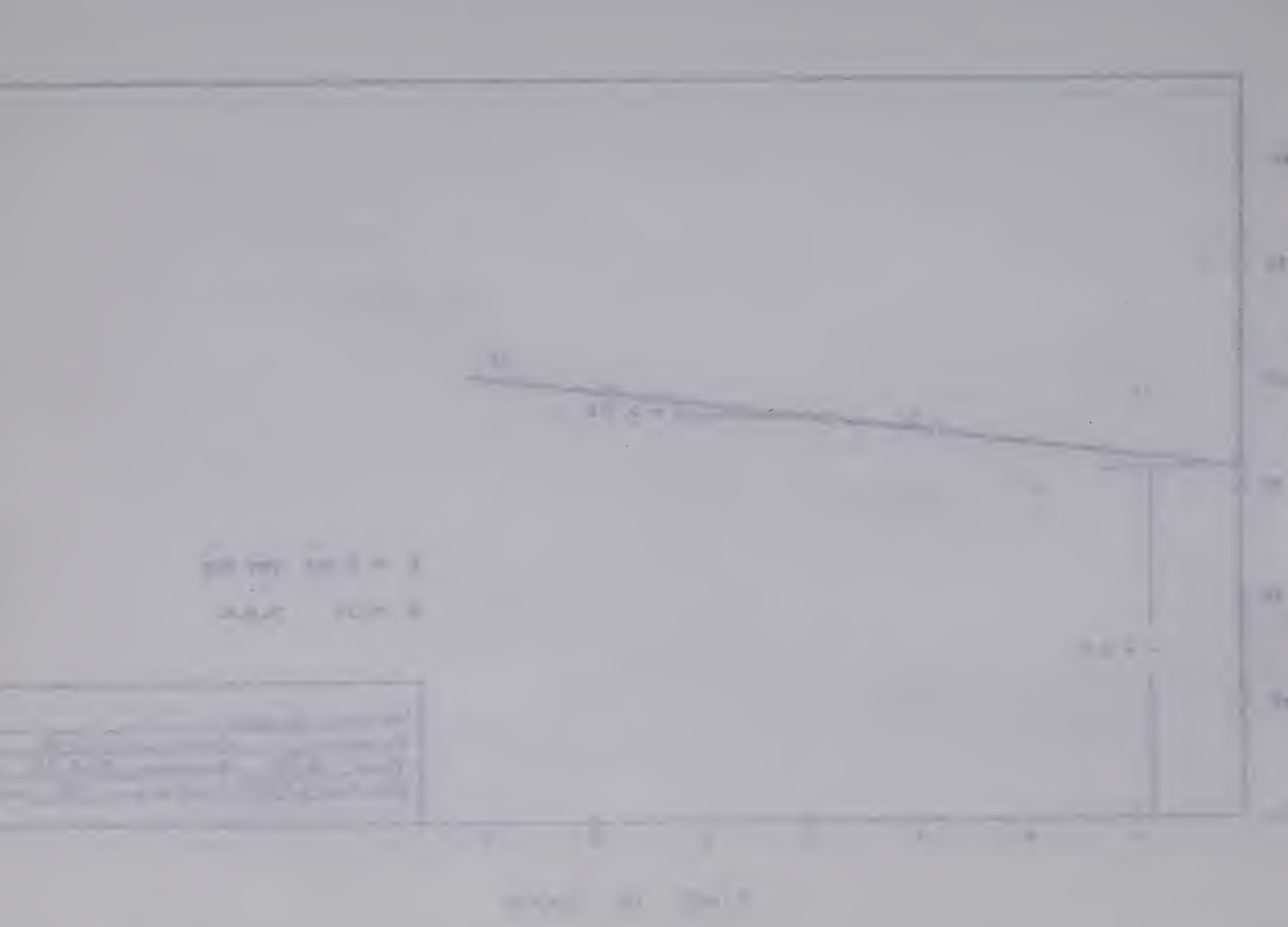


FIGURE: 4 - 10 B.O.D. CURVE CONSTANTS



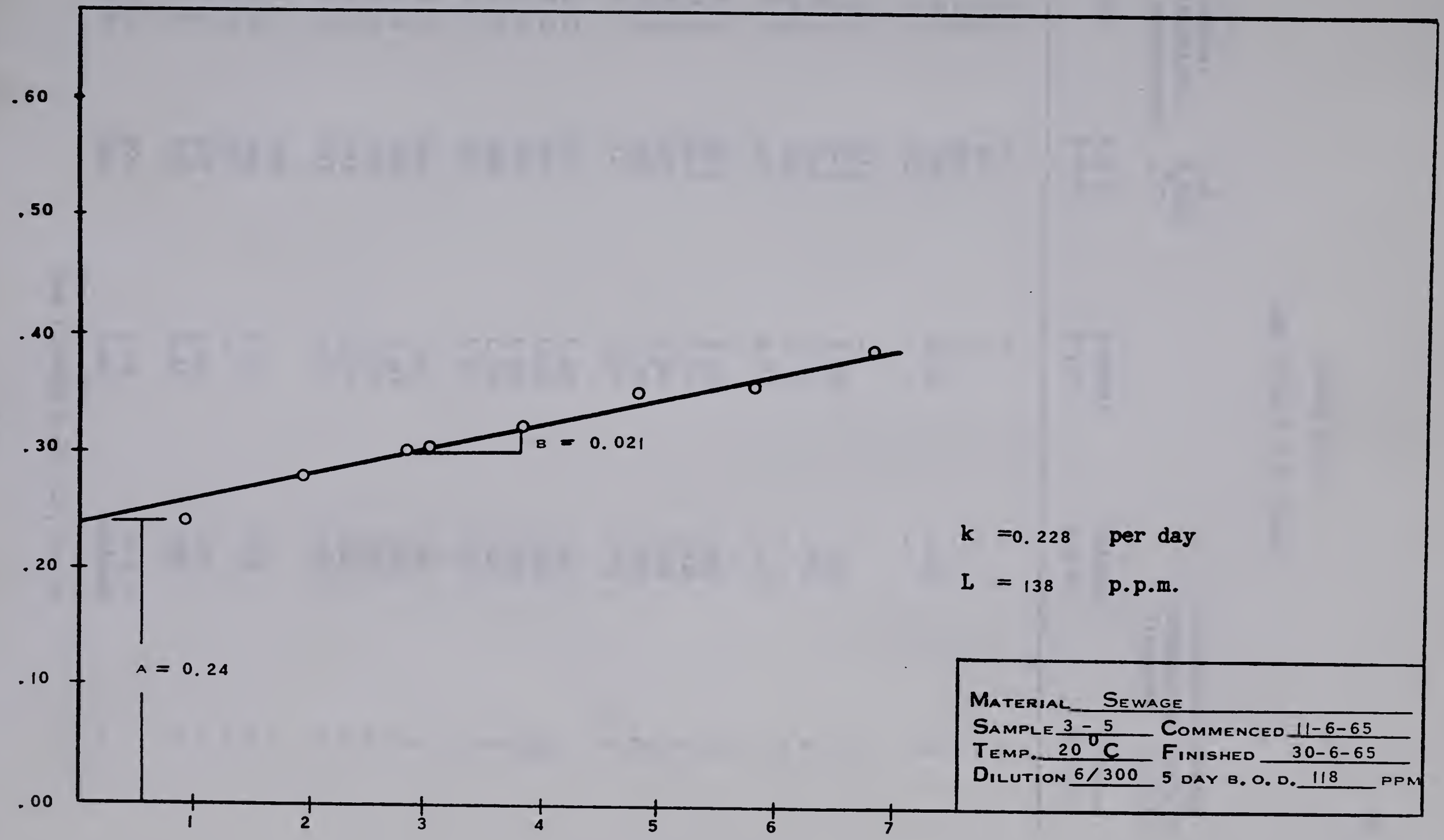


FIGURE: 4 -11 B. O. D. CURVE CONSTANTS

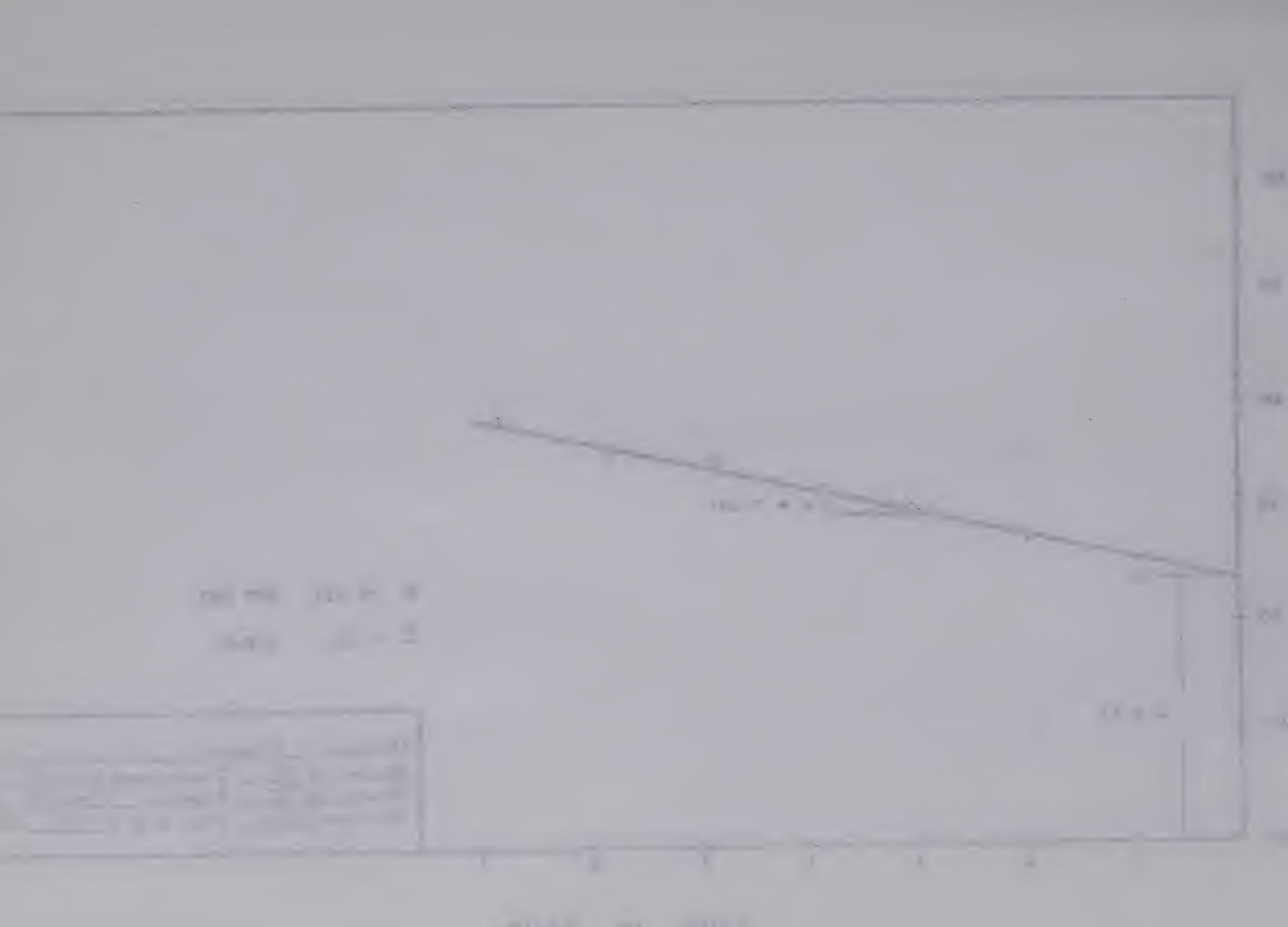


TABLE IV-9

LONG TERM B.O.D. DATA

Sample: 3-2
Dilution: 6/300
Temperature: 4°C

Material: Sewage
Commenced: 11/6/65
Finished: 20/9/65

Day	B.O.D. p.p.m.	Ammonia p.p.m.	Nitrite p.p.m.	Nitrate p.p.m.
0	-	-	-	-
0.8	10	-	-	-
1.9	85	-	-	-
2.7	105	1.34	.003	0
3.7	113	-	-	-
4.7	113	-	-	-
5.7	110	1.28	.004	-
6.7	110	1.44	.004	0
8.2	115	-	-	-
9.7	110	1.38	.003	-
11.7	135	1.34	.003	0
13.7	165	1.34	.002	0
16.7	195	1.34	.002	0
18.7	185	1.34	.002	0
24.2	215	1.38	.002	0
30.0	220	1.26	.002	-
36.0	225	1.38	.003	.03
39.0	235	1.44	.002	0
42.0	236	1.50	.002	0
46.0	253	1.47	.001	0
49.0	248	1.40	.002	0
53.0	248	1.40	.002	0
56.0	260	1.39	.001	0
60.0	251	1.39	.002	0
66.0	253	1.39	.002	0
73.0	260	-	-	-
74.0	260	1.39	.001	0
78.0	270	-	-	-
80.0	278	1.44	.003	-
87.0	275	1.34	.003	0
93.0	295	1.44	.001	-
100.0	308	1.44	spoiled	-

See FIGURES 4-12, 13, 14, 50

TABLE IV-11

LONG TERM B.O.D. DATA

Sample: 3-6 Material: Sewage (Acidized)
Dilution: 6/300 Commenced: 11/6/65
Temperature: 4°C Finished: 16/8/65

Day	B.O.D. p.p.m.	Ammonia p.p.m.	Nitrite p.p.m.	Nitrate p.p.m.
0	-	-	-	-
1.0	5.0	-	-	-
1.9	7.5	-	-	-
2.7	32.5	1.24	.003	-
3.7	70.0	-	-	-
4.7	68.0	-	-	-
5.7	80.0	-	-	-
6.7	80.0	1.34	.004	-
8.1	88.0	-	-	-
9.7	90.0	1.16	.004	0
11.7	90.0	1.16	.004	0
13.7	103.0	1.20	.003	0
16.7	100.0	-	-	-
18.7	113.0	1.16	.004	0
24.2	115.0	1.24	.003	0
30.0	115.0	1.16	.003	-
36.0	116.0	1.18	.004	0
49.0	163.0	1.20	.003	0
53.0	140.0	1.19	.003	0
56.0	143.0	1.18	.001	0
66.0	153.0	1.28	.003	0

See FIGURES 4-12, 13, 15, 51

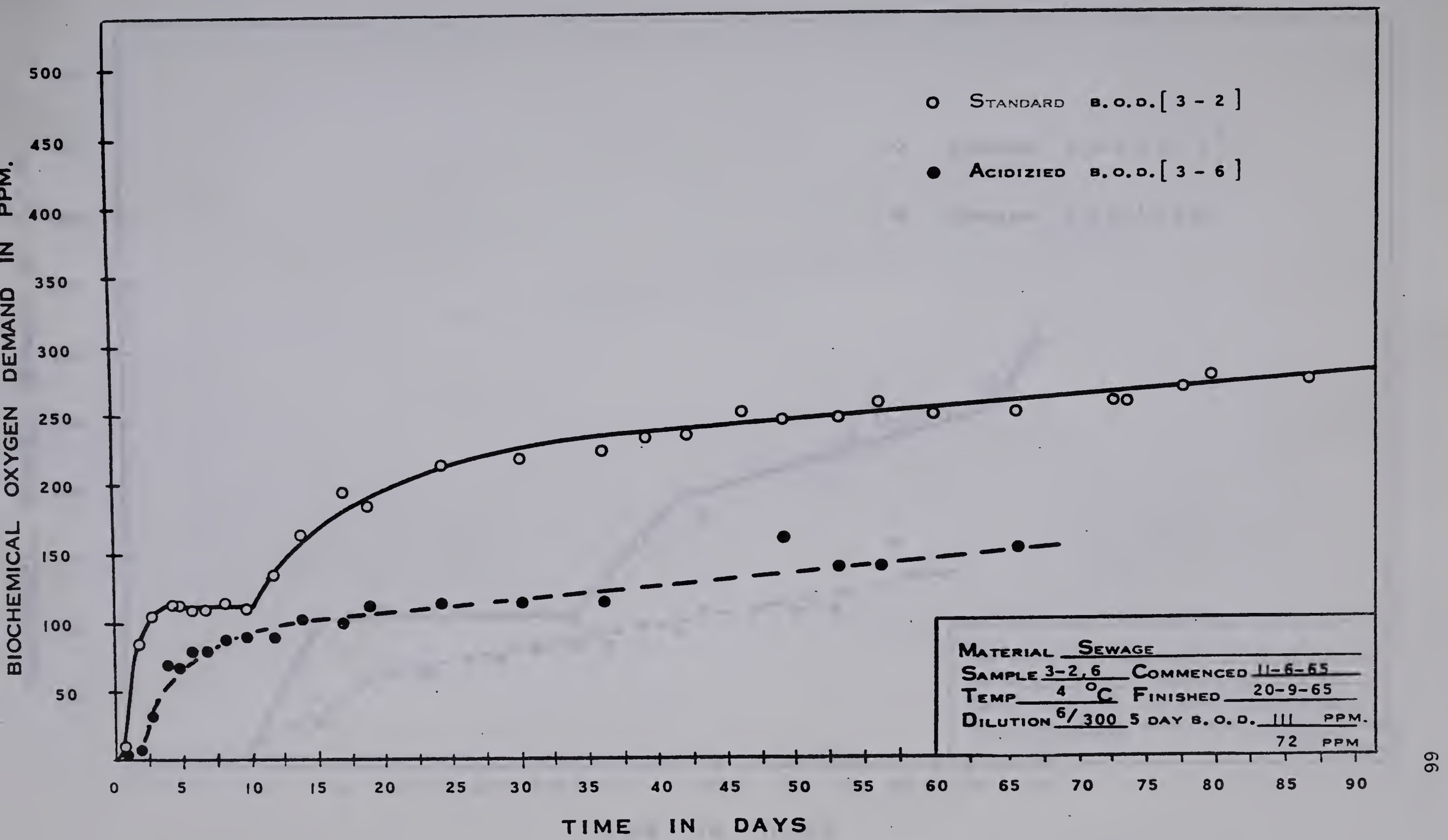
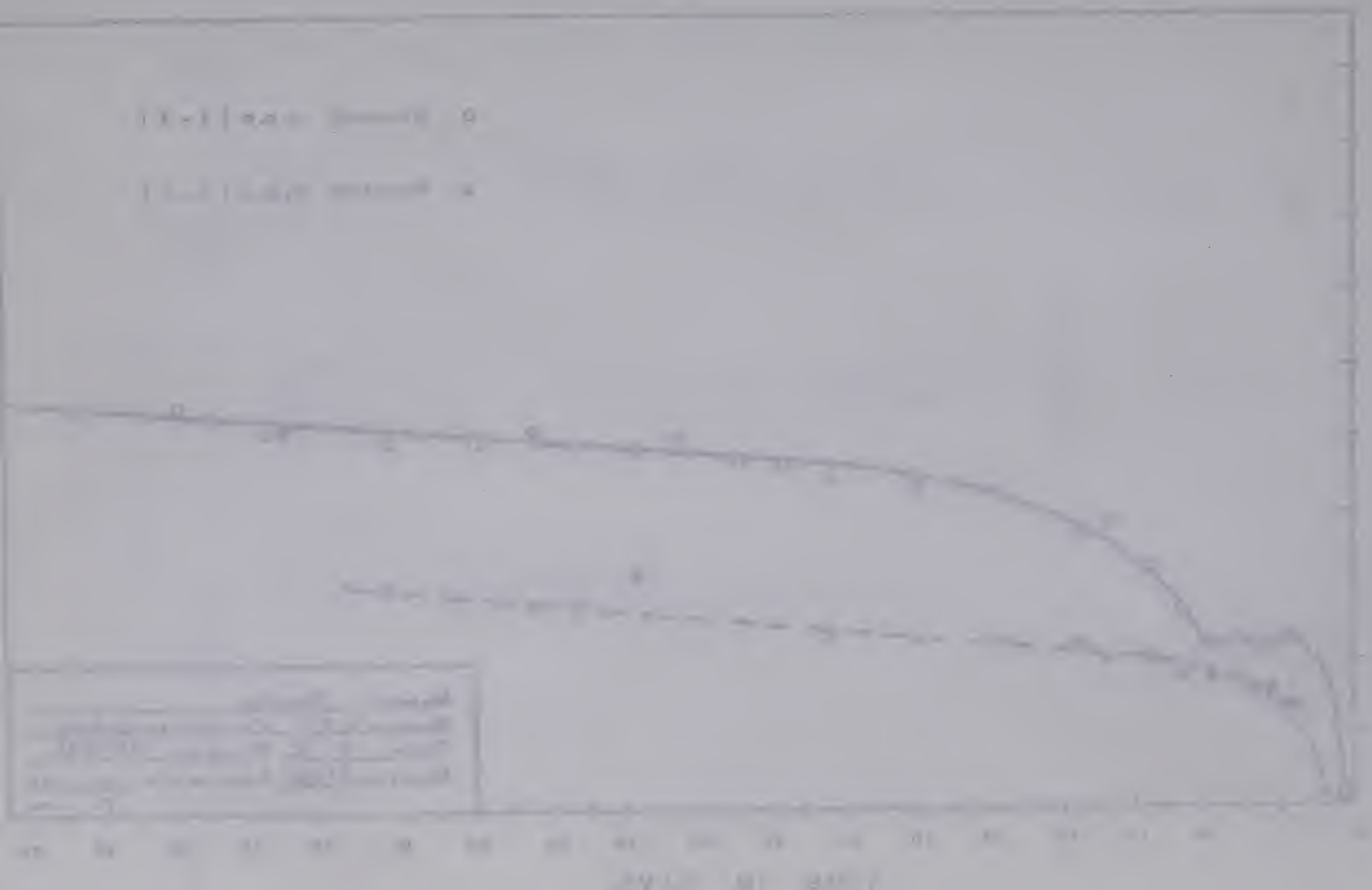


FIGURE: 4 - 12 NORMAL B. O. D. CURVE " ARITHMETIC PLOT "



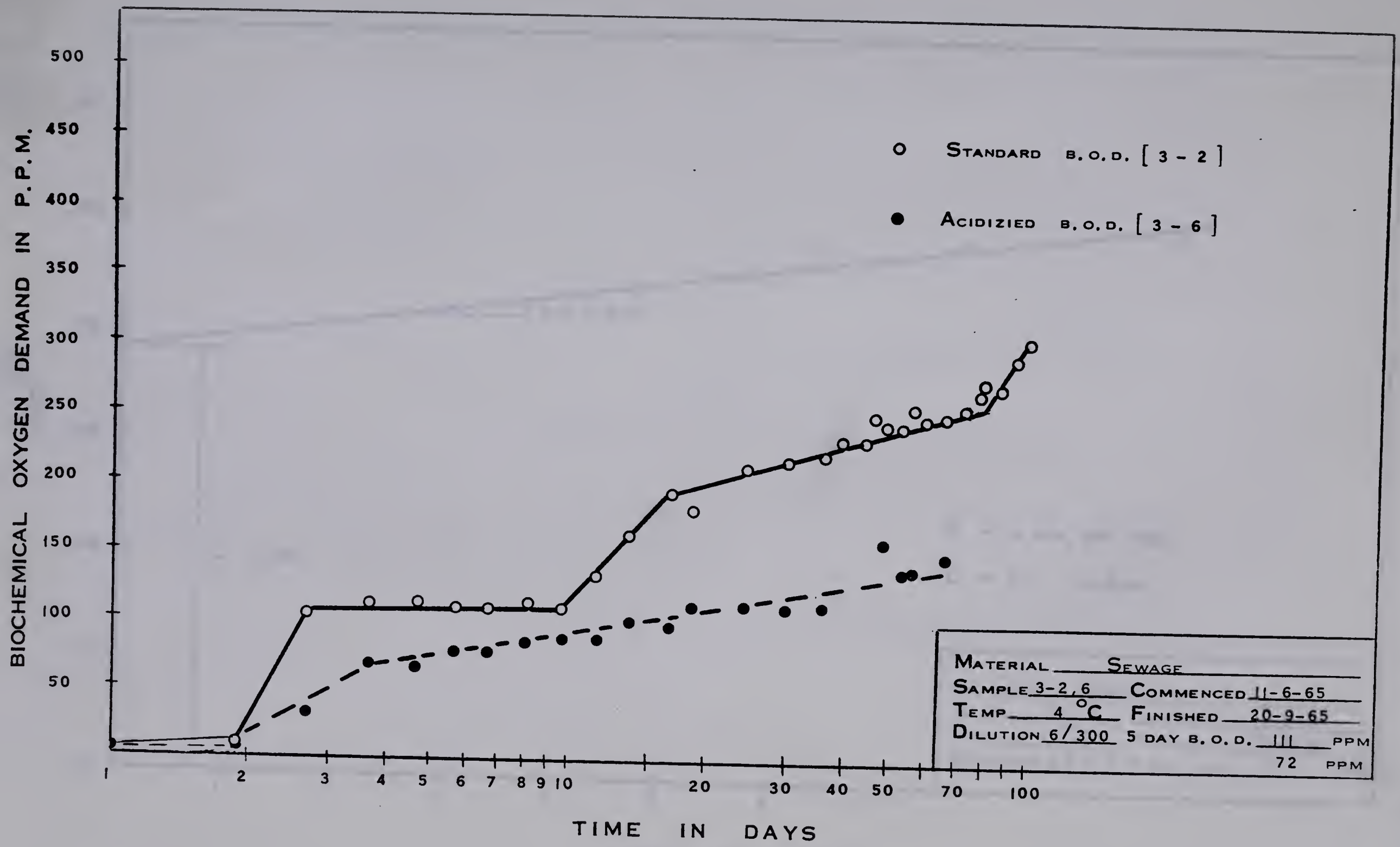
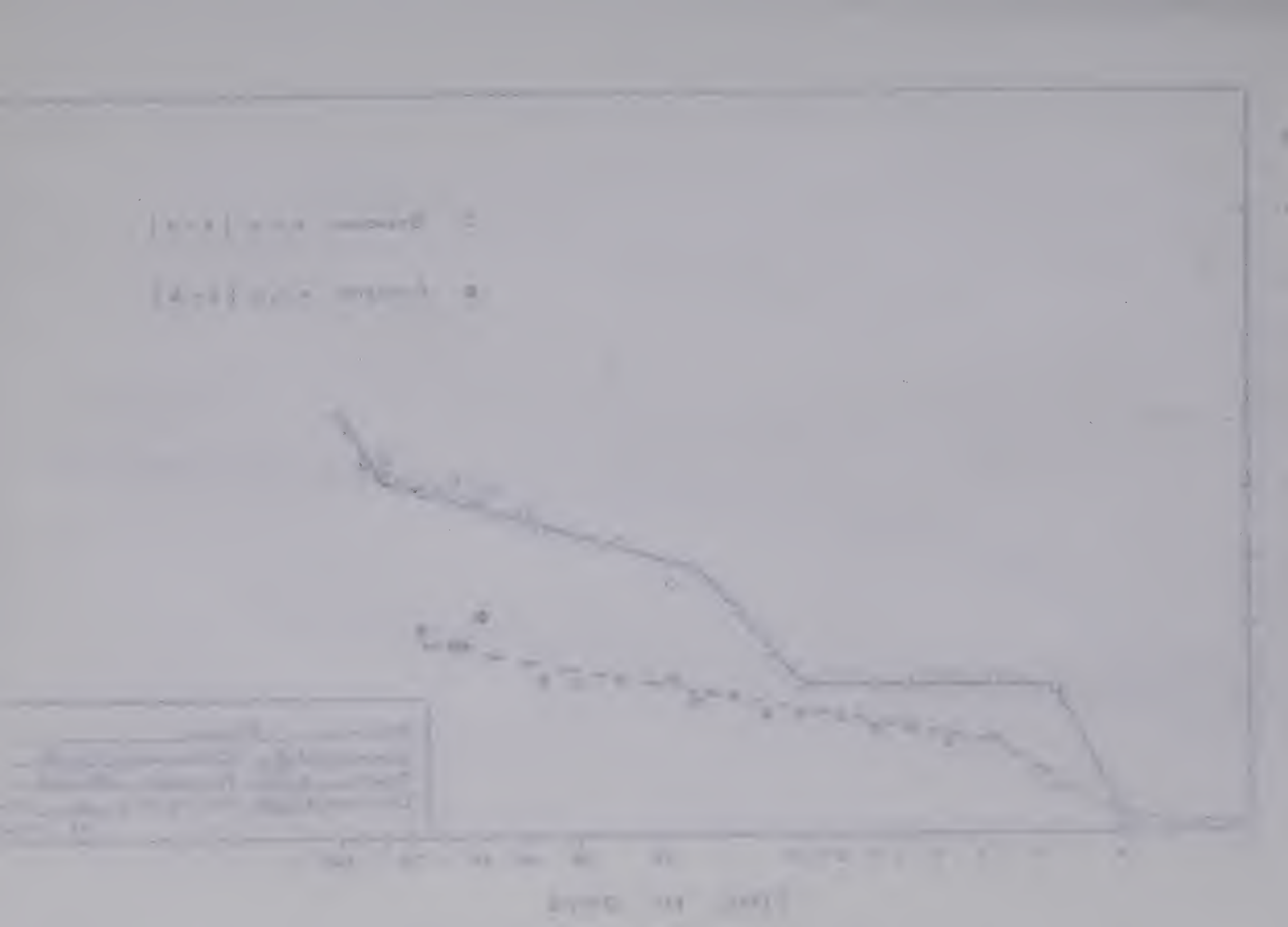


FIGURE: 4 - 13

B.O.D. CURVE "SEMI-LOG"



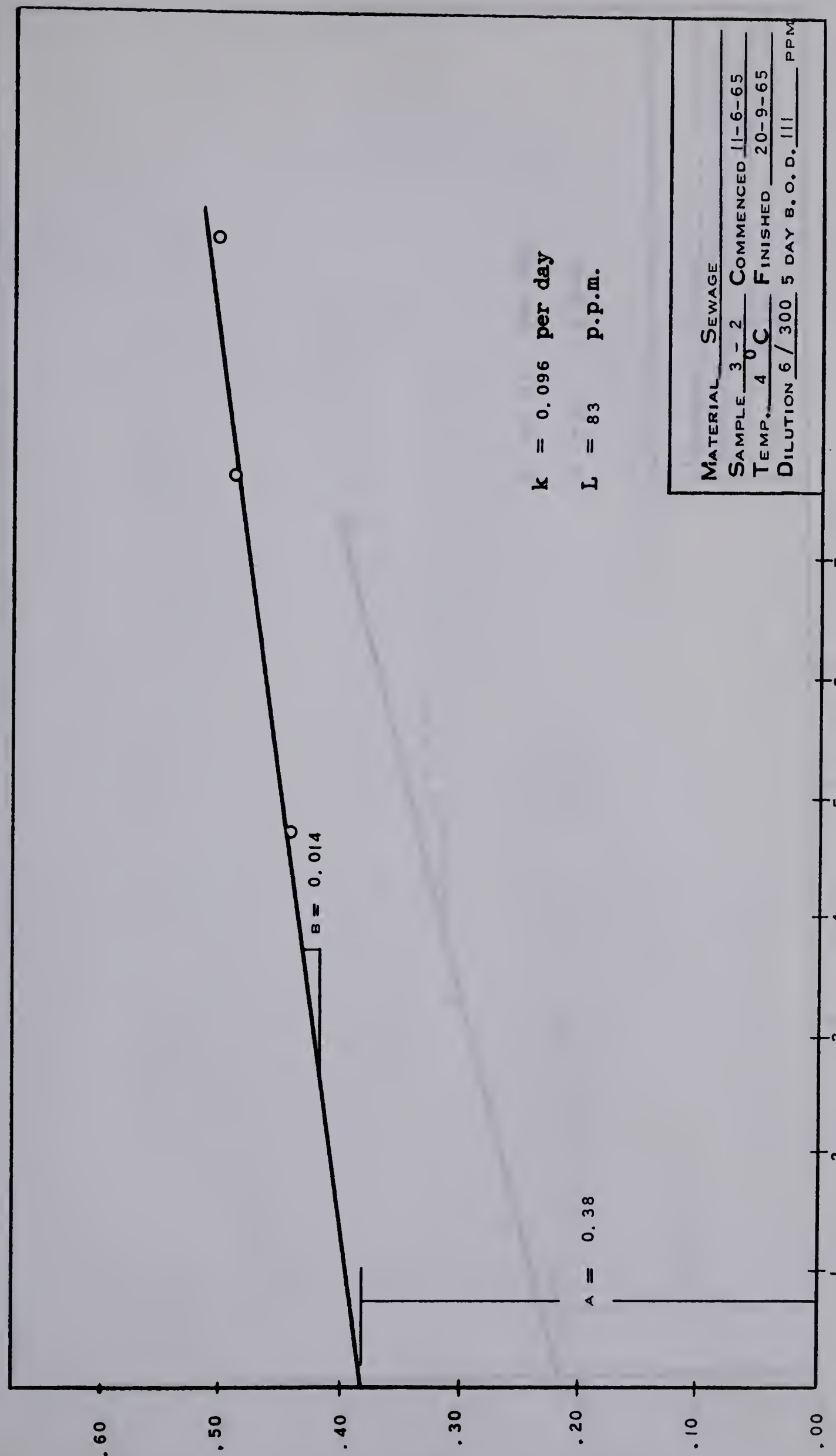
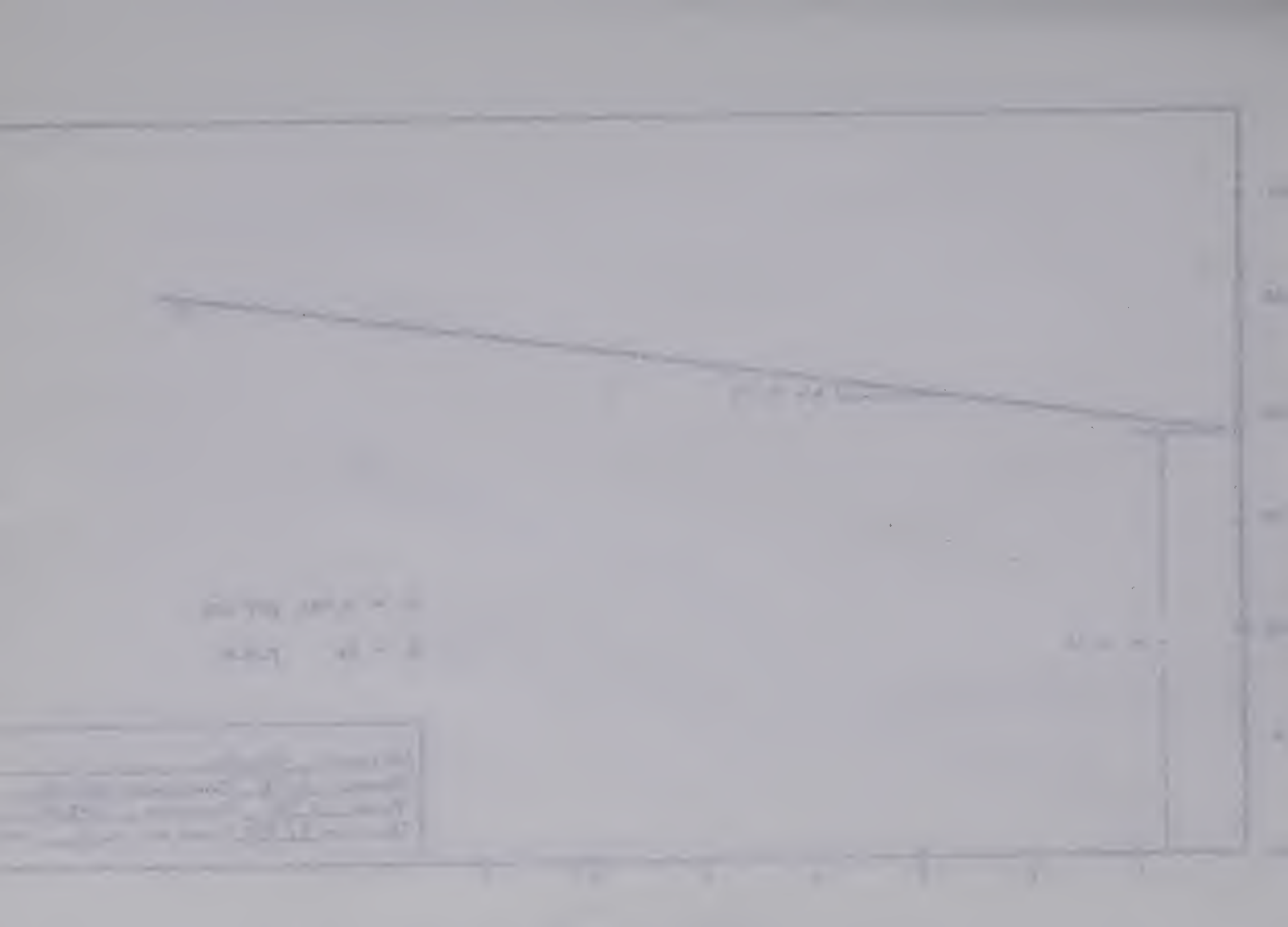


FIGURE: 4-14 B.O.D. CURVE CONSTANTS



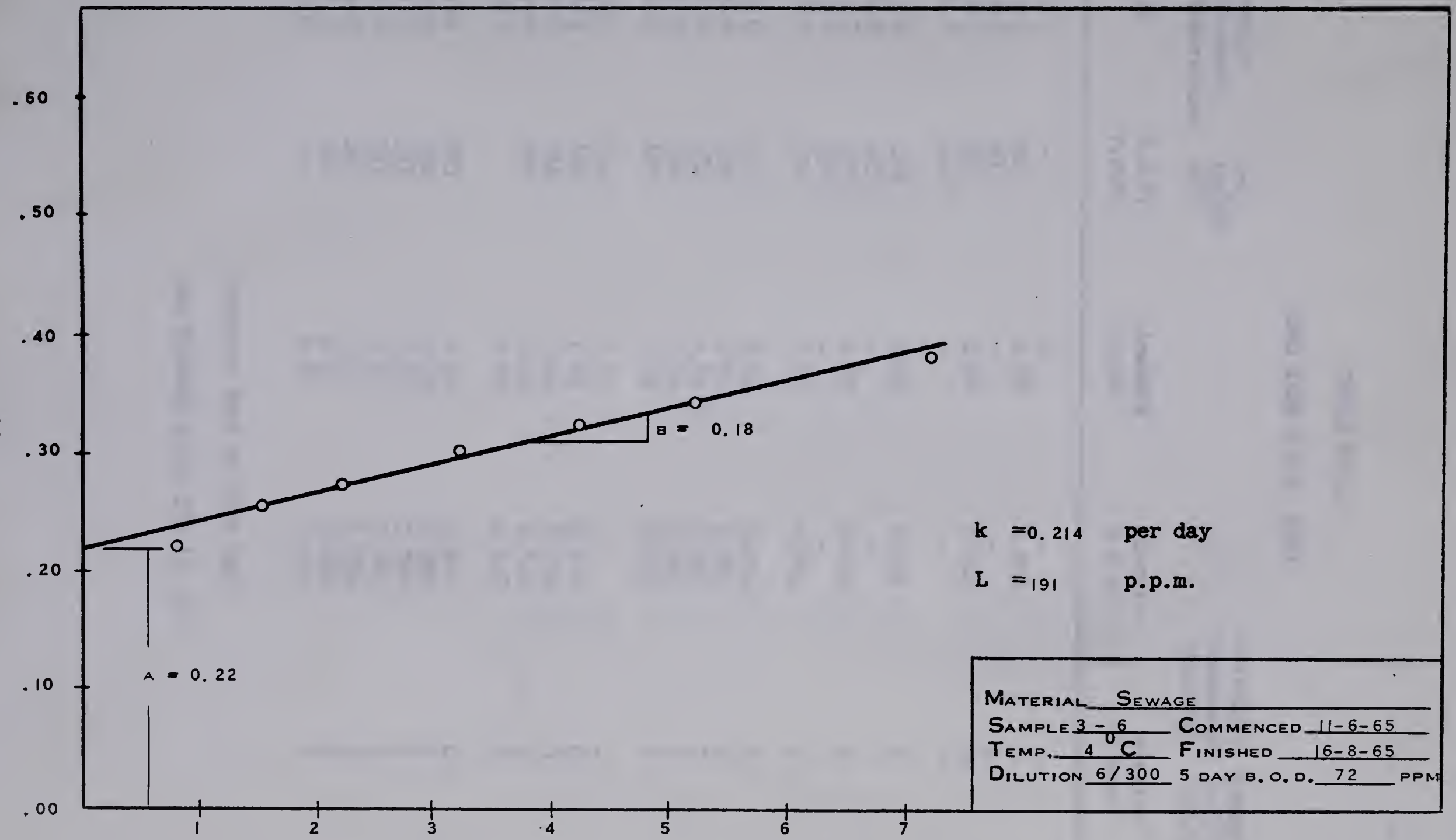


FIGURE: 4 - 15 B.O.D. CURVE CONSTANTS

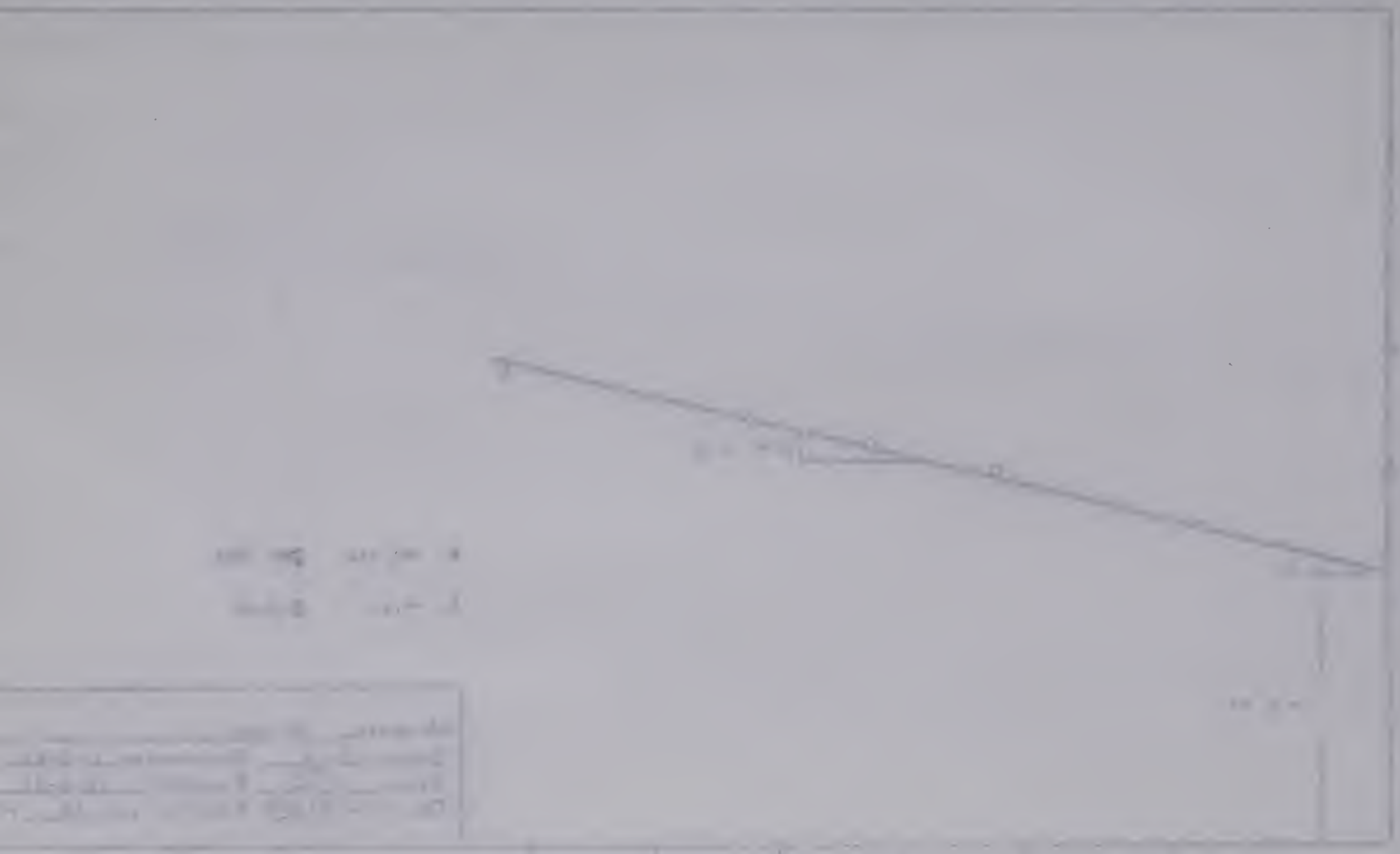


TABLE IV-12

LONG TERM B.O.D. DATA

Sample: 4-1 Material: Sewage
Dilution: 12/300 Commenced: 16/7/65
Temperature: 20°C Finished: 11/8/65

Day	B.O.D. p.p.m.	Ammonia p.p.m.	Nitrite p.p.m.	Nitrate p.p.m.
0	-	-	-	-
1.1	48	1.82	0.003	0
2.3	83	-	-	-
3.0	97	1.86	0.004	.02
4.0	114	-	-	-
5.0	118	1.86	0.003	0
6.0	123	-	-	-
7.0	129	1.98	0.004	0
7.2	130	-	-	-
9.0	132	1.86	0.004	0
10.0	142	2.04	0.004	0
11.0	150	1.82	0.006	0
12.0	154	2.04	0.007	0
13.0	154	1.92	0.009	0
14.0	157	1.92	0.057	0
15.0	159	2.03	-	-
16.5	174	1.62	0.370	0
18.0	264	1.04	1.210	0
19.0	300	0.20	1.740	0
18.5		0.40	1.540	0
19.2	303	0.19	2.200	0
20.0	332	0.16	1.680	0
21.0	333	0.17	1.750	0
22.0	333	0.22	1.780	0
24.3	345	0.13	1.790	0
25.0	341	0.07	1.830	0
26.0	-	0.14	1.420	0

Incubator down on 27th day

See FIGURES 4-16, 17, 18, 52

TABLE IV-13

LONG TERM B.O.D. DATA

Sample: 4-2
Dilution: 12/300
Temperature: 20°C

Material: Sewage (Acidized)
Commenced: 16/7/65
Finished: 11/8/65

Day	B.O.D. p.p.m.	Ammonia p.p.m.	Nitrite p.p.m.	Nitrate p.p.m.
0	-	-	-	-
1.0	3.8	1.82	.003	0
2.2	43	-	-	-
2.8	55	1.75	.003	0
3.8	64	-	-	-
4.8	64	1.94	.003	0
5.8	79	-	-	-
6.8	86	1.90	.003	0
8.8	92	1.80	.004	0
10.8	99	1.83	.003	0
12.8	99	1.94	.003	0
13.8	105	1.90	.003	0
17.8	114	1.94	.002	0
19.8	109	1.89	.003	0
20.8	110	1.80	.005	0
22.2	109	1.82	.003	0
24.3	120	1.90	.003	0
25.0	111	1.90	.003	0
26.0	121	1.90	.003	0

Incubator down on 27th day

See FIGURES 4-16, 17, 19, 52

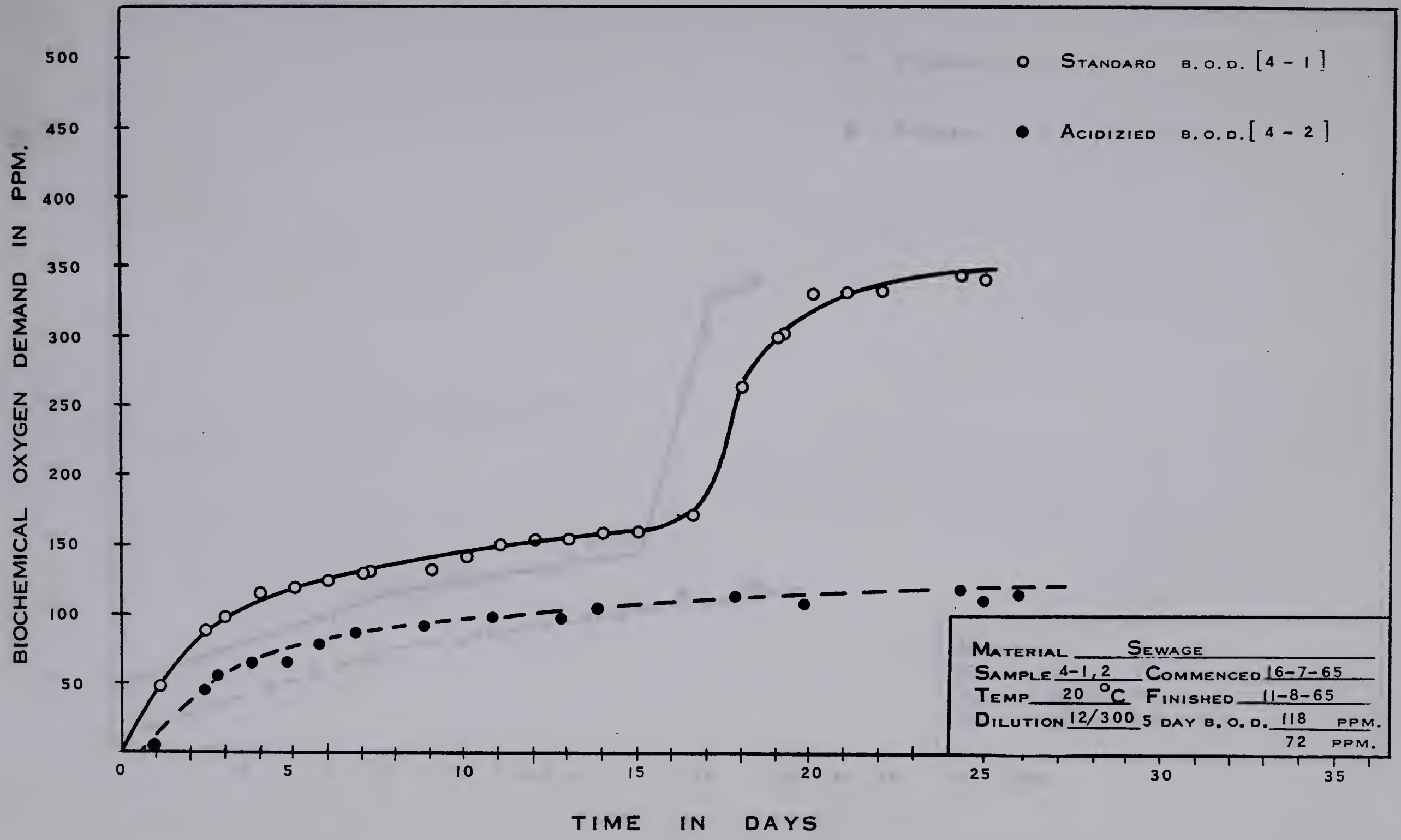
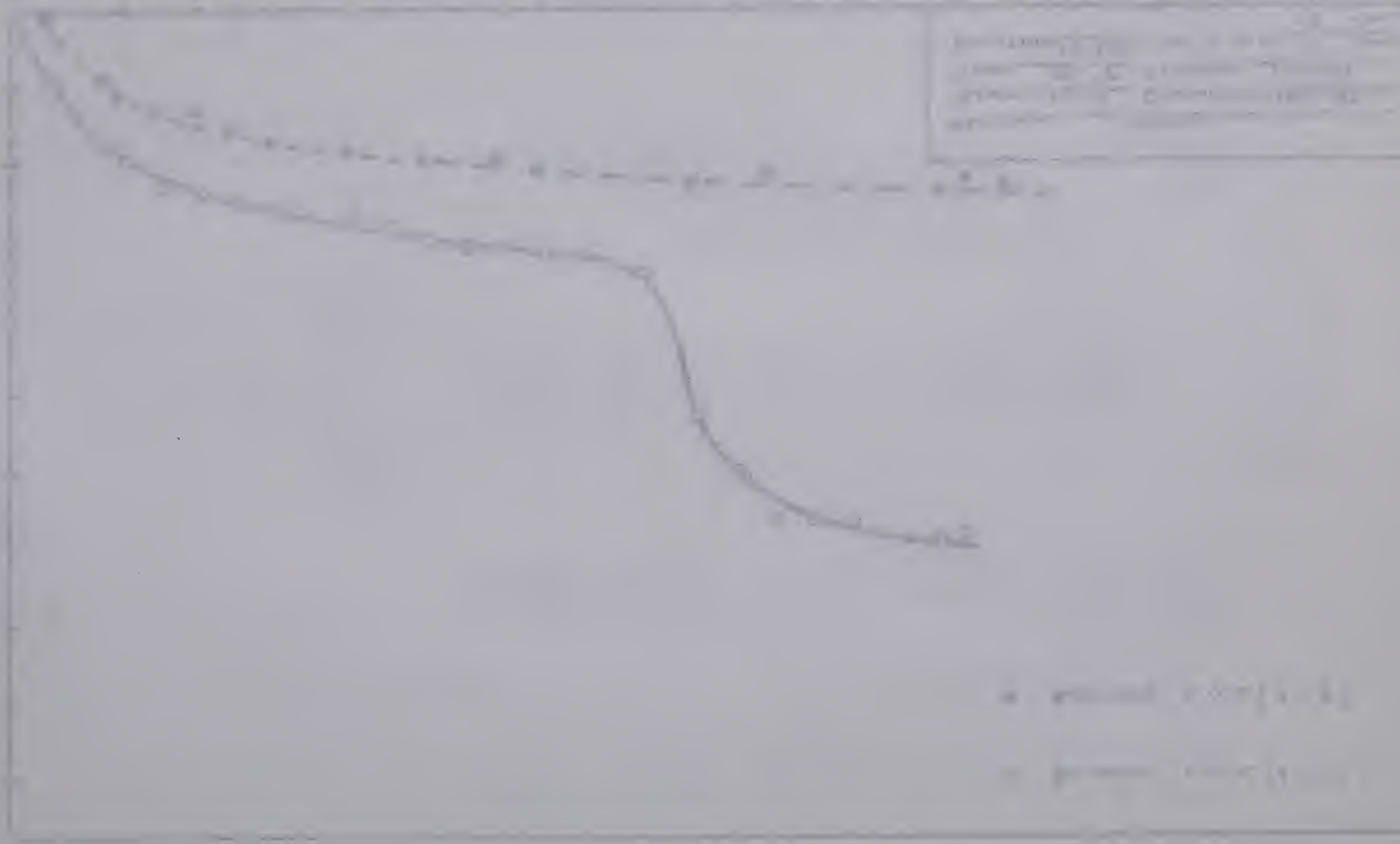


FIGURE: 4 - 16 NORMAL B. O. D. CURVE " ARITHMETIC PLOT "



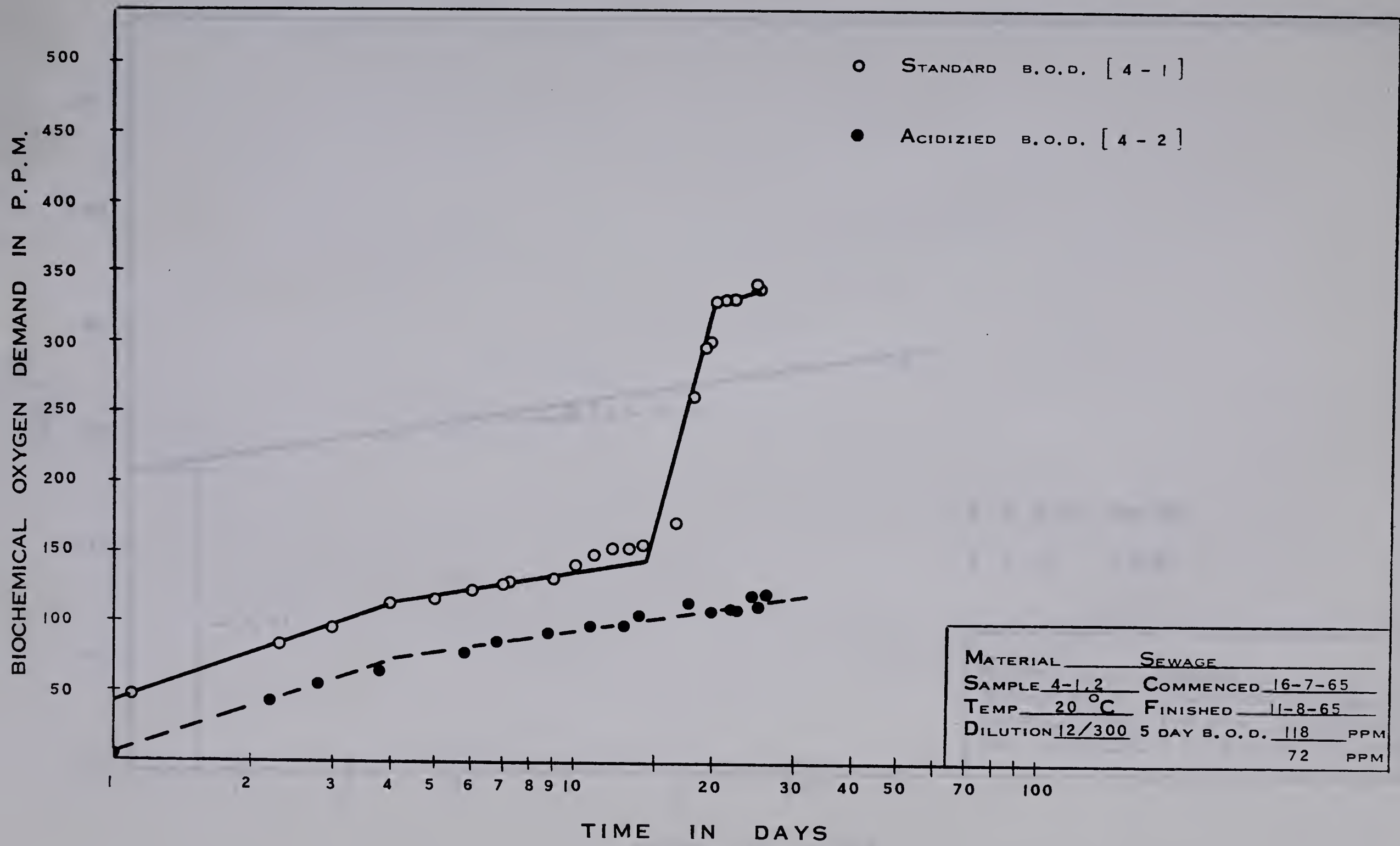
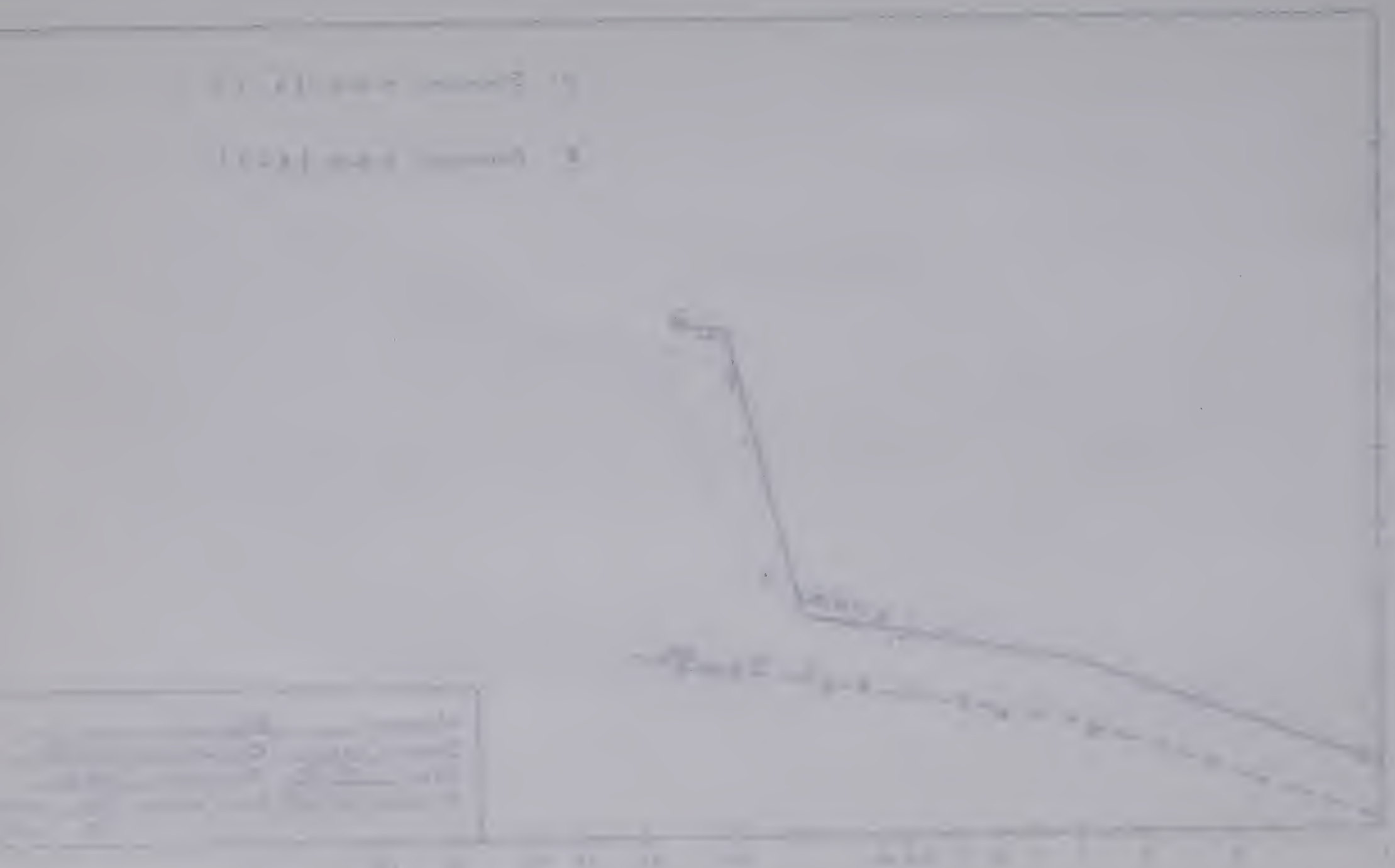


FIGURE: 4 - 17

B.O.D. CURVE "SEMI-LOG"



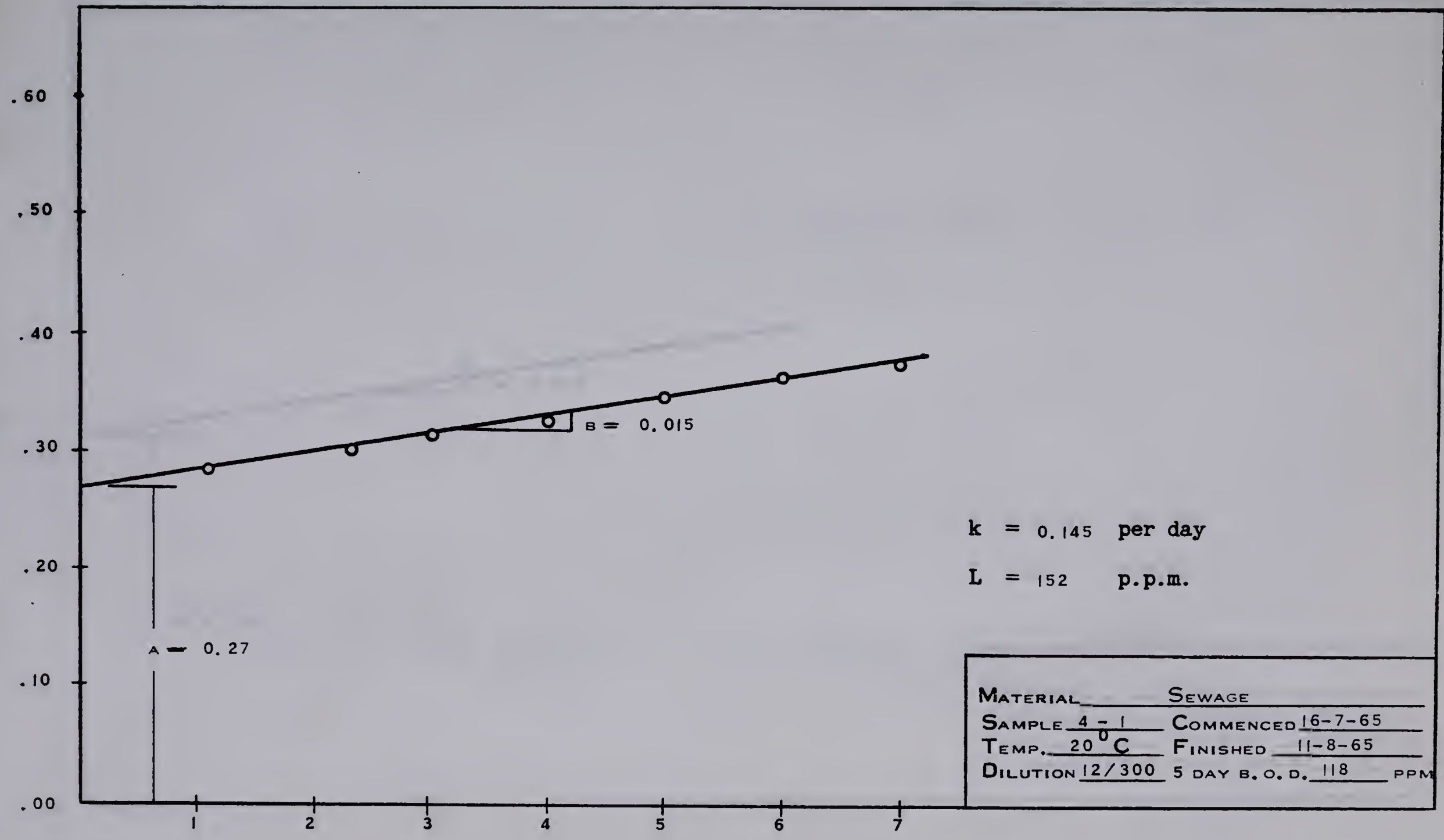
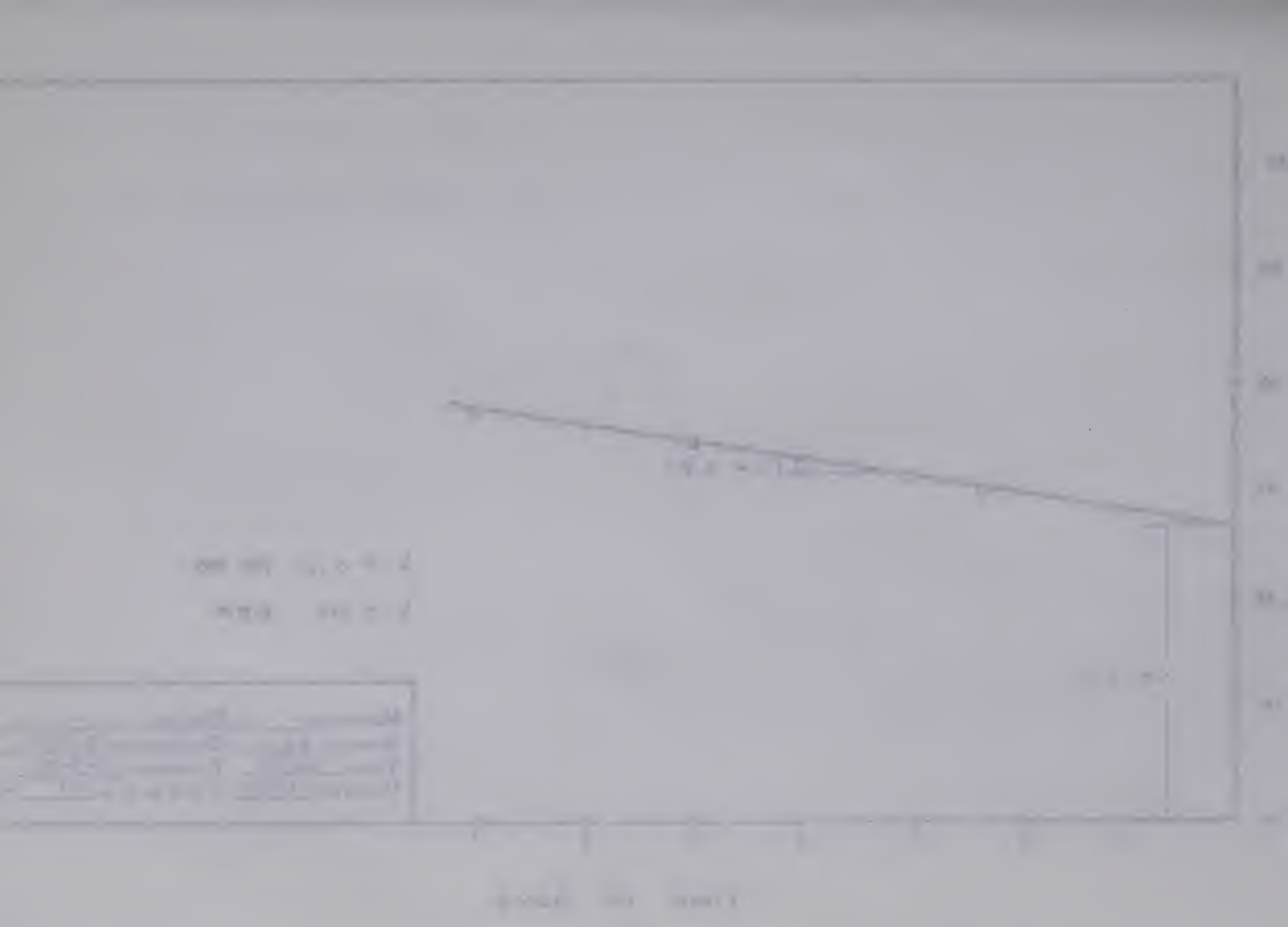


FIGURE: 4 - 18 B.O.D. CURVE CONSTANTS



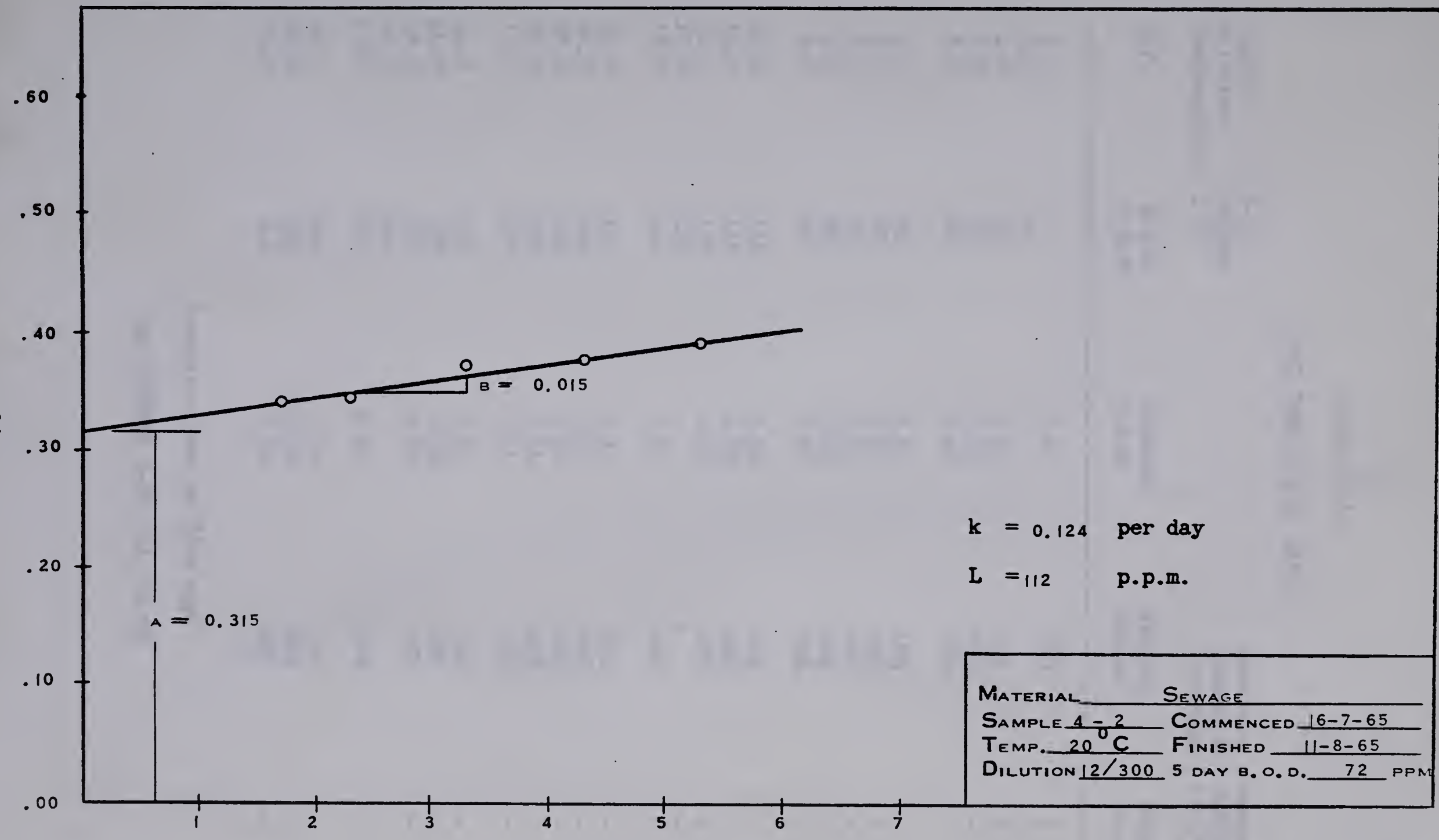


FIGURE: 4 - 19 B.O.D. CURVE CONSTANTS

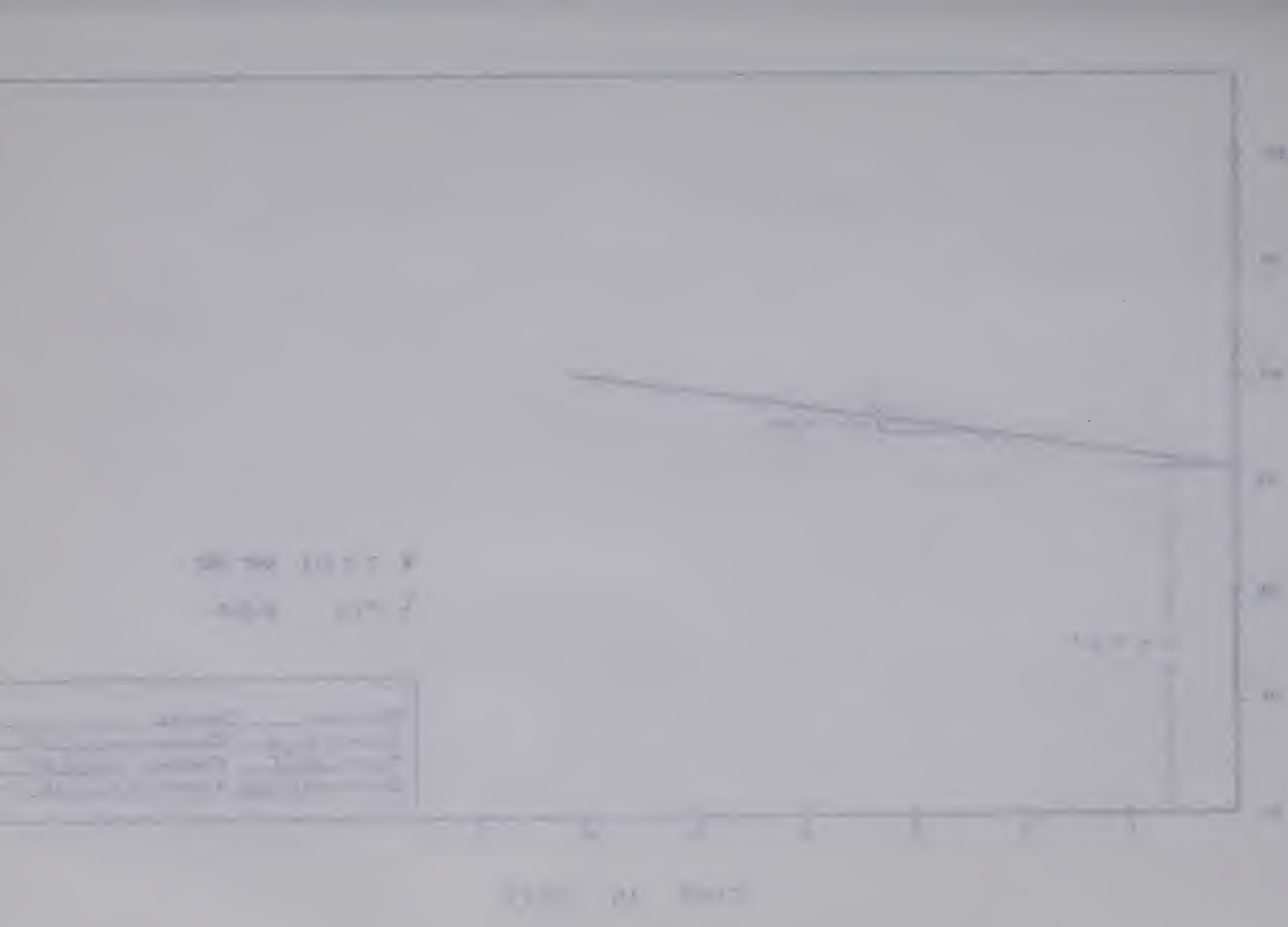


TABLE IV-14

LONG TERM B.O.D. DATA

Sample: 6-1 Material: Sewage
Dilution: 20/300 Commenced: 24/8/65
Temperature: 4°C Finished: 8/11/65

Day	B.O.D. p.p.m.	Ammonia p.p.m.	Nitrite p.p.m.	Nitrate p.p.m.
0	-	2.61	.003	0
0.12	8	-	-	-
1.0	14	2.50	.004	0
2.0	32	2.50	.005	-
3.0	61	2.40	.004	-
4.0	66	2.40	.004	-
6.0	77	2.32	.004	0
7.0	81	2.37	.005	-
8.0	86	2.40	.004	-
9.0	99	2.40	.004	-
10.0	110	2.50	.004	-
12.0	116	2.50	.004	-
14.0	129	2.40	.003	0
15.0	129	-	-	-
17.0	141	2.31	.002	-
20.0	163	2.31	.001	-
22.0	164	2.31	.003	-
27.0	179	2.18	.003	-
30.0	188	2.31	.003	-
37.0	190	2.31	.002	-
41.0	194	2.31	.002	-
44.0	199	2.40	.002	-
49.0	197	2.50	.003	-
50.0	206	-	-	-
56.0	212	2.40	.002	-
60.0	209	2.30	.002	-
71.0	230	2.30	.003	-
76.0	246	2.30	.003	-

Incubator down on 76th day

See FIGURES 4-20, 21, 22,53

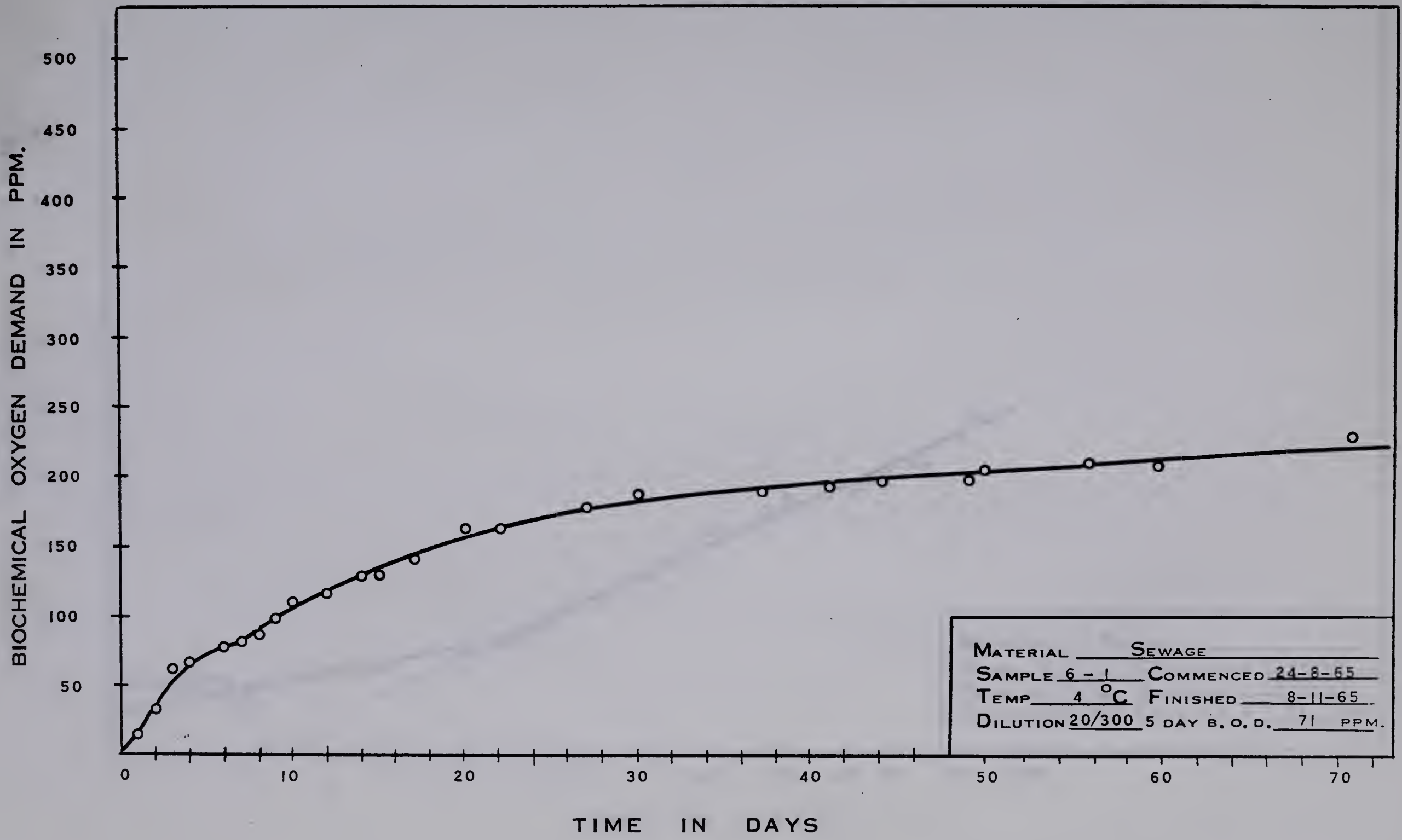
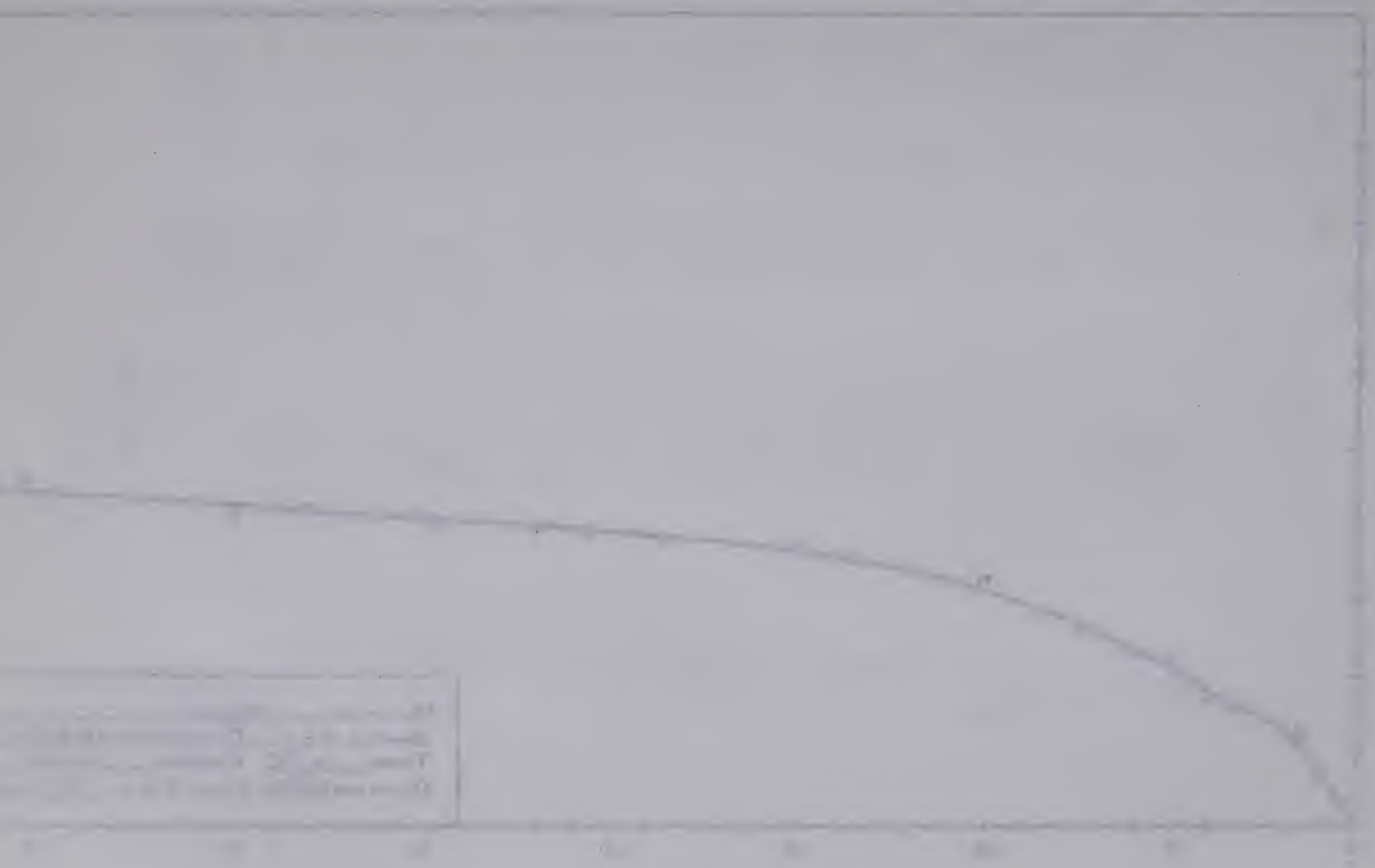


FIGURE: 4 - 20 NORMAL B. O. D. CURVE " ARITHMETIC PLOT "



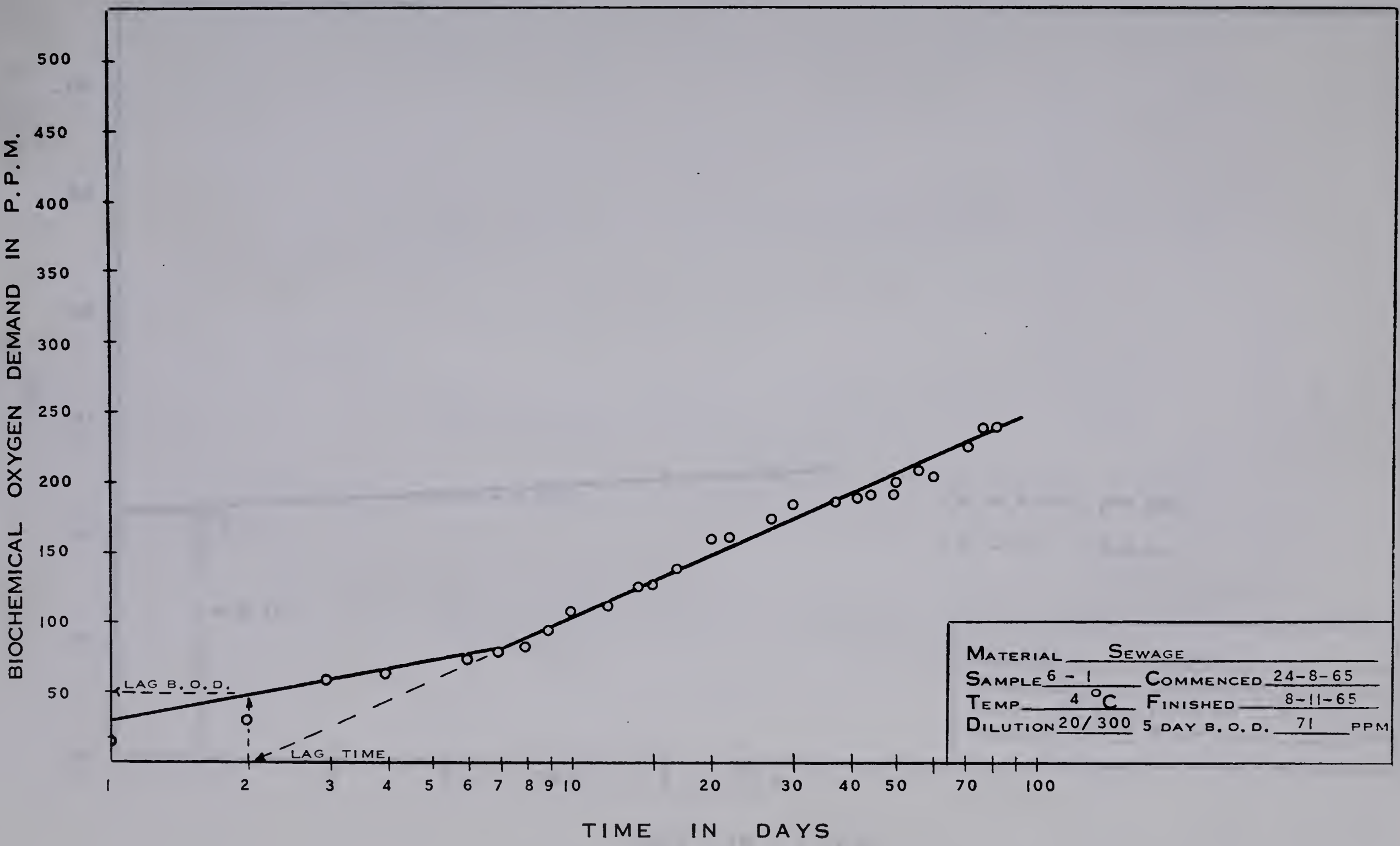
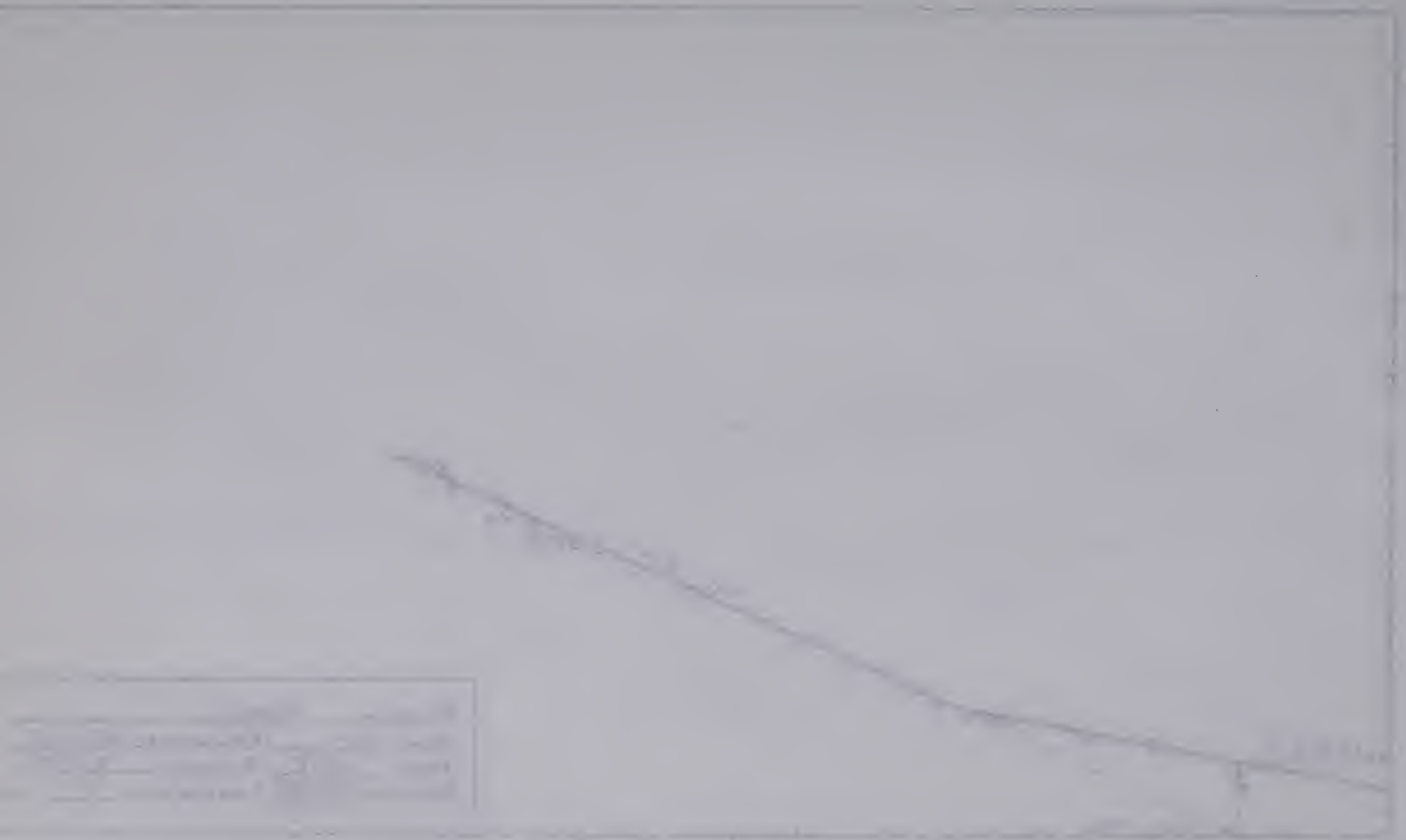


FIGURE:4 - 21

B.O.D. CURVE "SEMI-LOG"



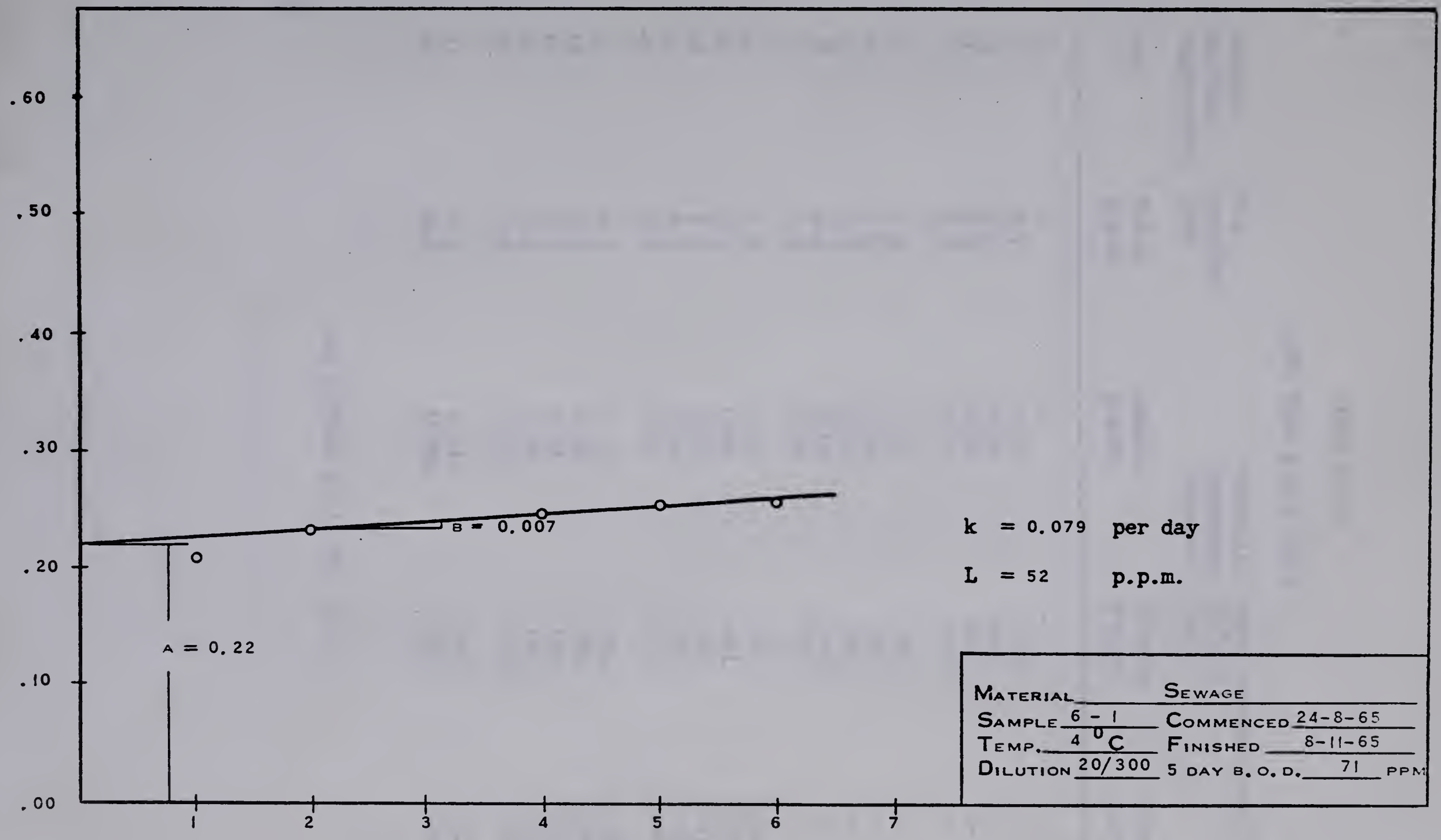


FIGURE: 4 - 22 B. O. D. CURVE CONSTANTS

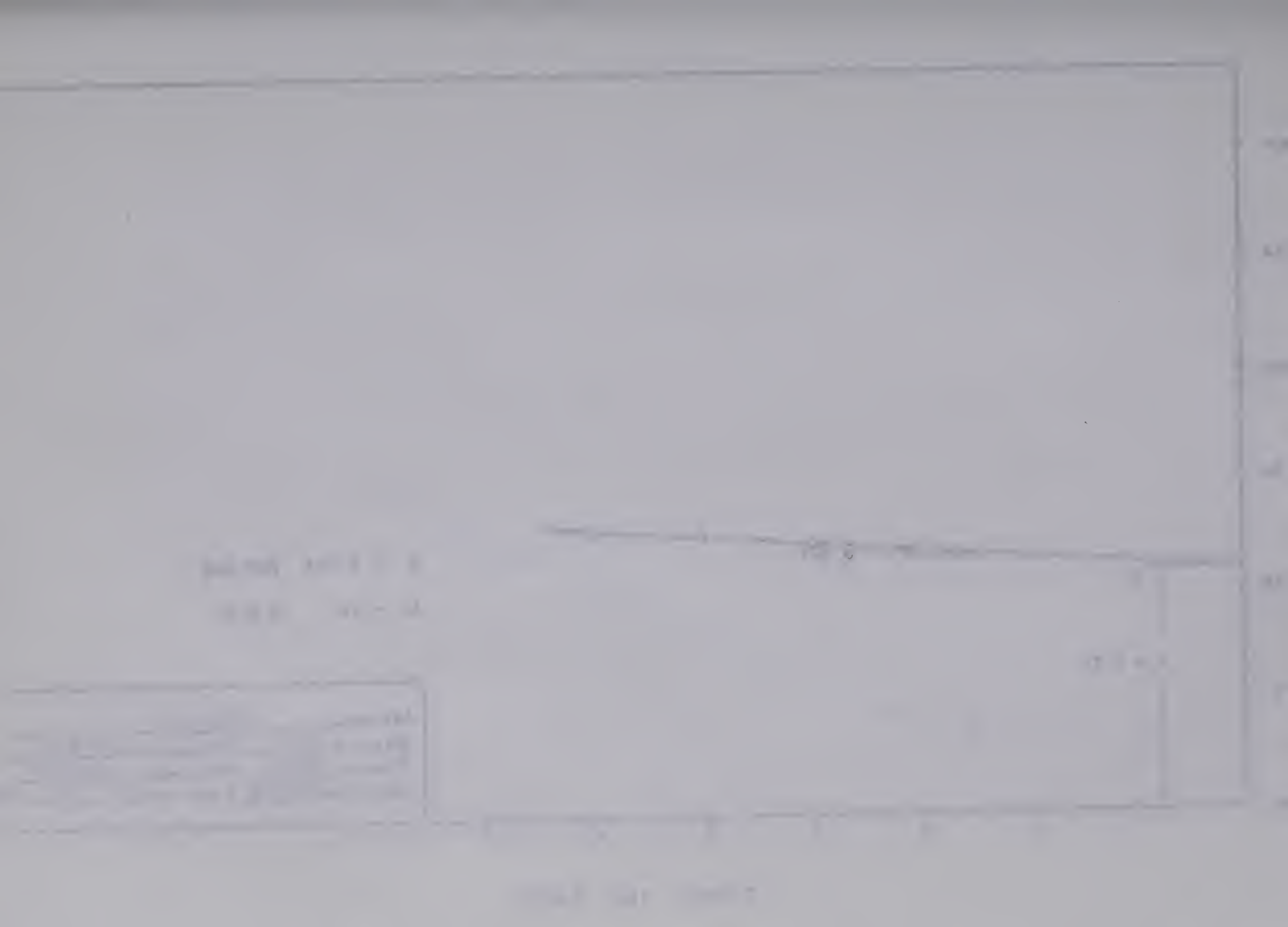


TABLE IV-15

LONG TERM B.O.D. DATA

Sample: 9-1 Material: North Saskatchewan River
Dilution: straight Commenced: 16/10/65
Temperature: 20°C Finished: 11/11/65

Day	B.O.D. p.p.m.	Ammonia p.p.m.	Nitrite p.p.m.	Nitrate p.p.m.
0	-	-	-	-
1	0.7	0.38	.008	-
2	2.2	0.30	.011	-
3	2.2	0.35	.024	-
4	3.7	0.35	.040	-
5	3.8	0.35	.036	-
6	4.0	0.32	.056	-
7	3.9	0.28	.094	-
8	4.1	0.12	.140	-
9	5.2	0.08	.033	-
10	5.7	0.06	.001	0.30
11	5.5	0.04	.001	0.31
12	5.8	0.01	.002	0.37
14	6.0	0.04	.001	0.43
16	6.6	0.01	.001	0.60
17	6.5	0.12	.001	0.58
18	7.5	0.06	.002	0.53
19	7.1	0.07	.001	0.48
20	7.4	0.06	.001	0.55
22	7.6	0.06	.001	0.49
23	7.4	0.012	.001	0.42
26	8.8	0.004	.001	0.44

See FIGURES 4-23, 24, 25, 60

TABLE IV-16

LONG TERM B.O.D. DATA

Sample: 9-2
Dilution: -
Temperature: 20°C

Material: North Saskatchewan River, Cylinder A
Commenced: 16/10/65
Finished: 13/11/65

Day	B.O.D. p.p.m.	Ammonia p.p.m.	Nitrite p.p.m.	Nitrate p.p.m.
0	-	-	-	-
1	0.6	.40	.008	-
3	2.3	.43	.007	-
4	2.9	.35	.008	-
5	3.3	.35	.006	-
6	3.5	.36	.006	-
7	4.2	.28	.005	-
8	4.4	.36	.004	-
9	4.9	.32	.003	-
10	5.4	.36	.002	-
11	5.7	.28	.002	-
12	6.1	.36	.002	0.11
14	6.7	.28	.002	-
16	7.7	.24	-	-
17	8.2	.26	.004	-
18	8.9	.16	.006	-
19	9.7	.16	.008	0.30
20	10.4	.06	.009	-
21	10.9	.10	.005	-
22	11.6	.07	.003	0.40
23	12.1	.08	.002	-
24	12.7	.04	.000	-
26	14.0	.04	.002	0.30
28	16.0	.04	-	0.37

See FIGURES 4-23, 24, 26, 60

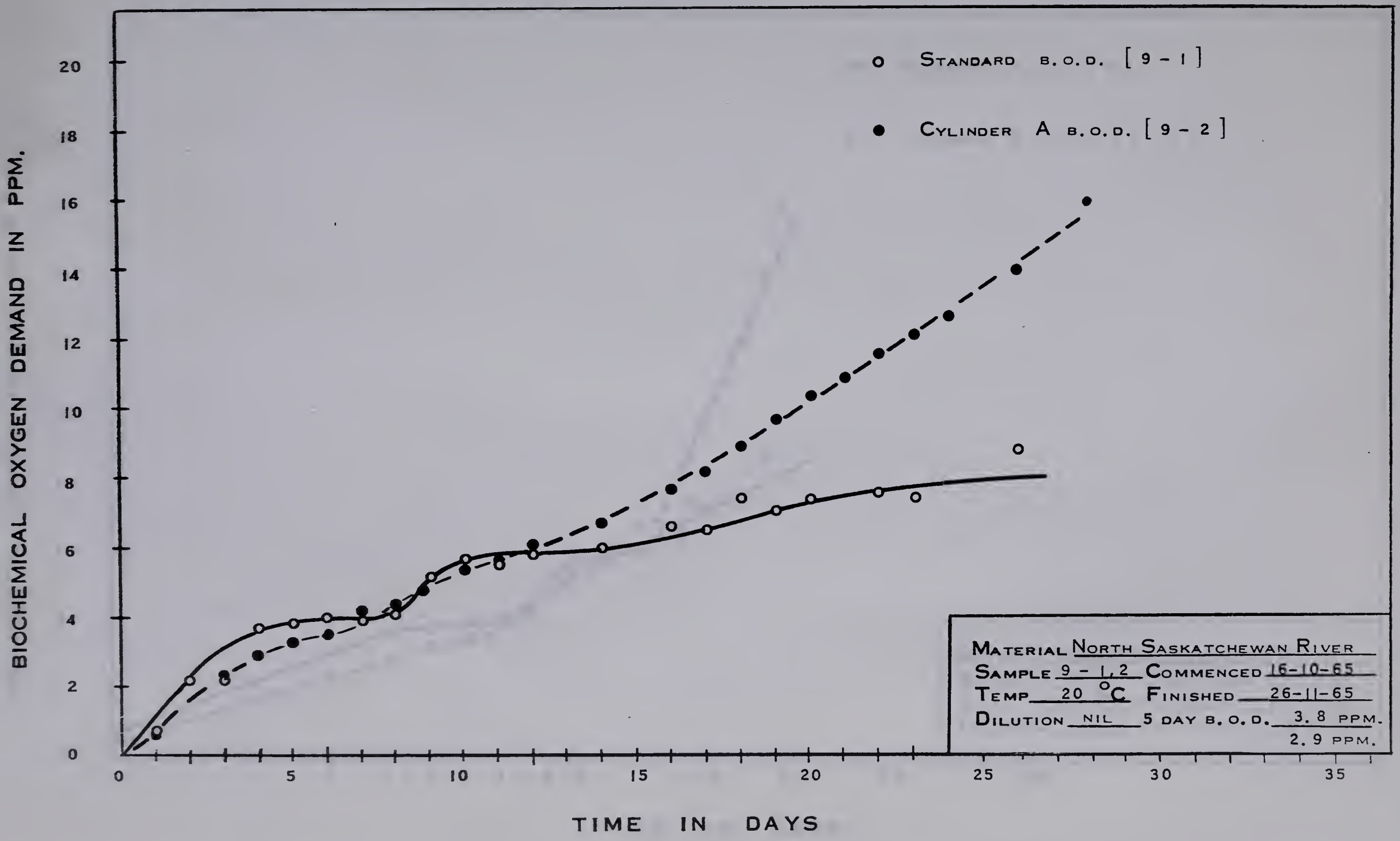
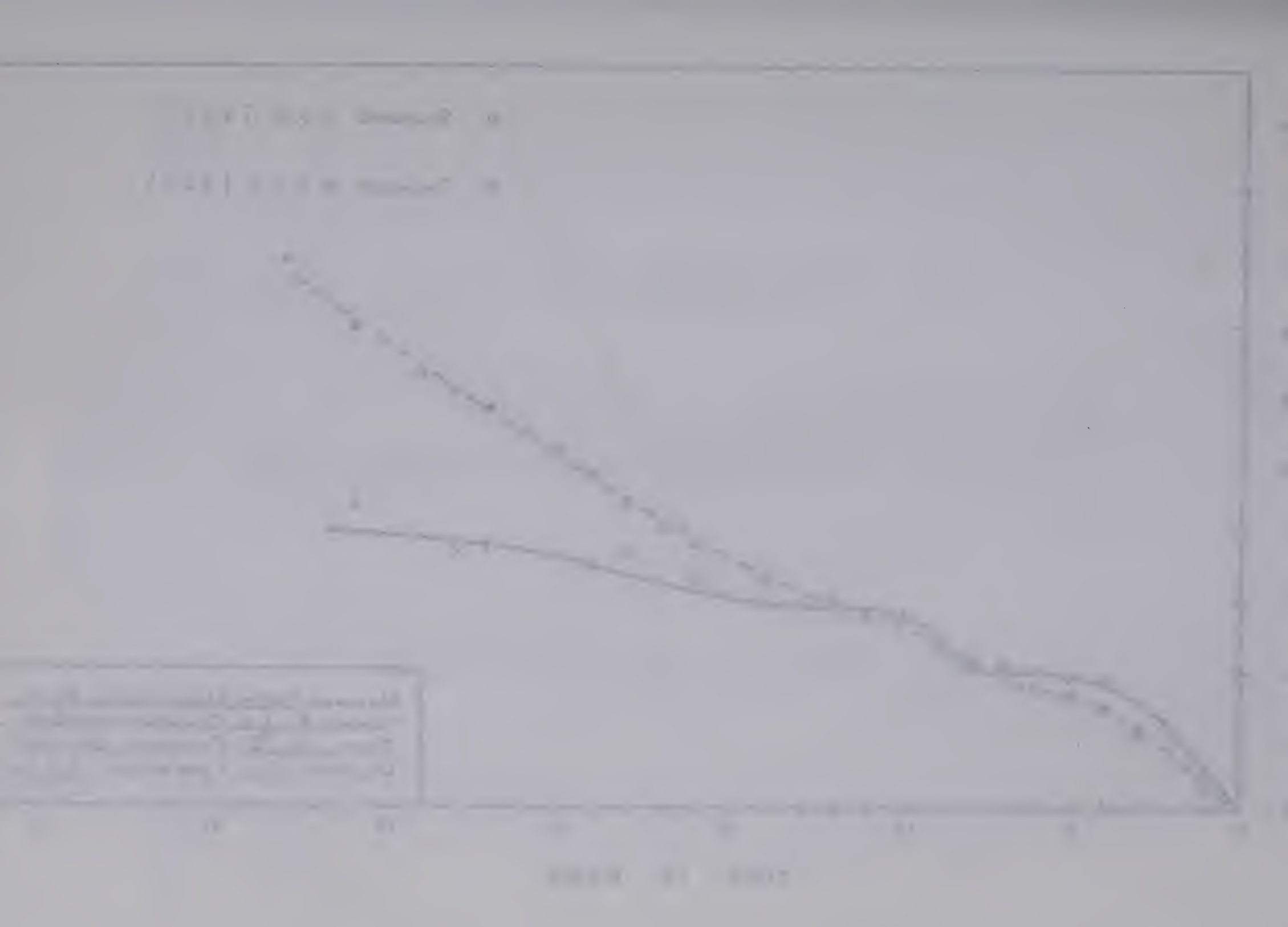


FIGURE: 4 - 23 NORMAL B. O. D. CURVE " ARITHMETIC PLOT "



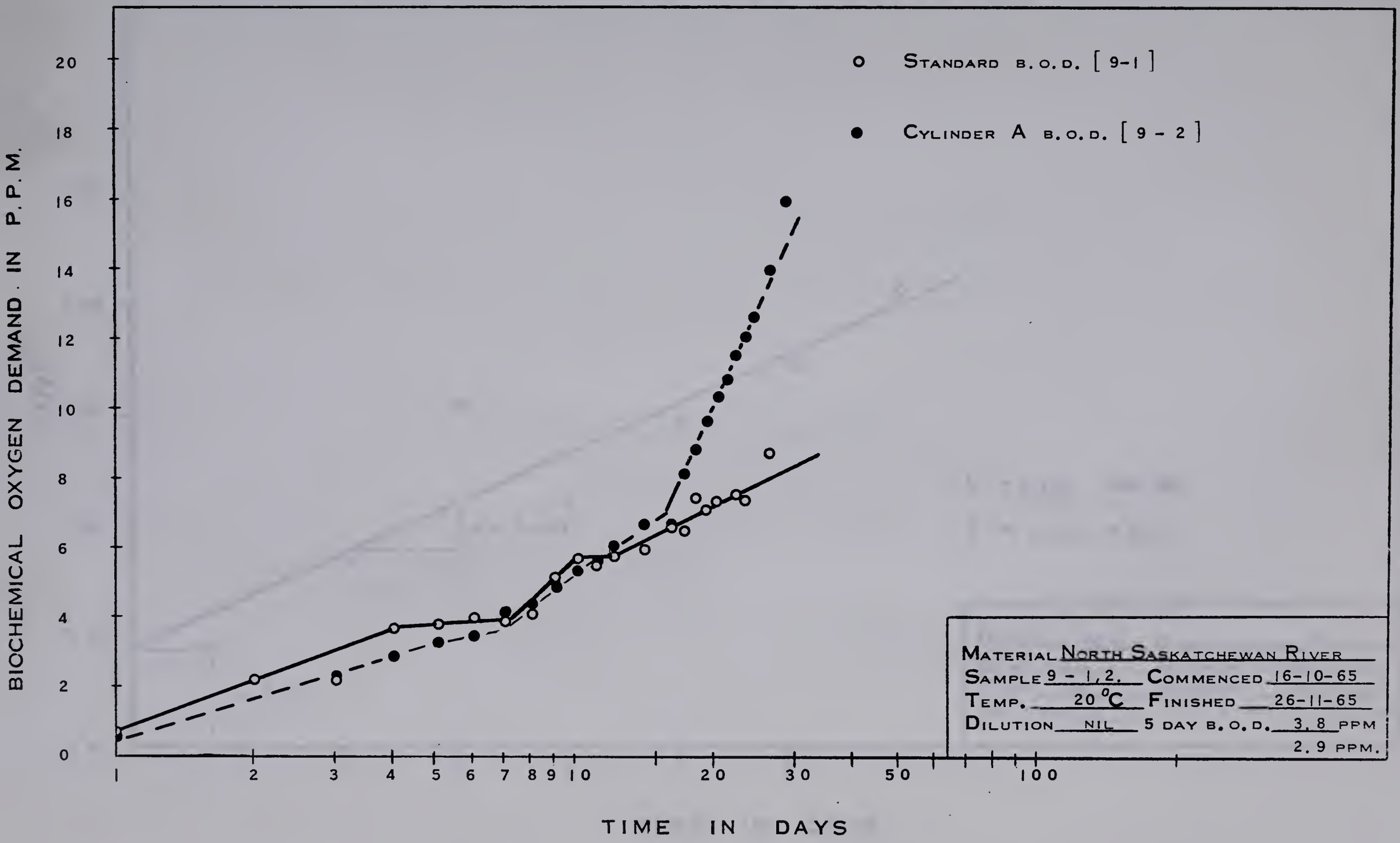
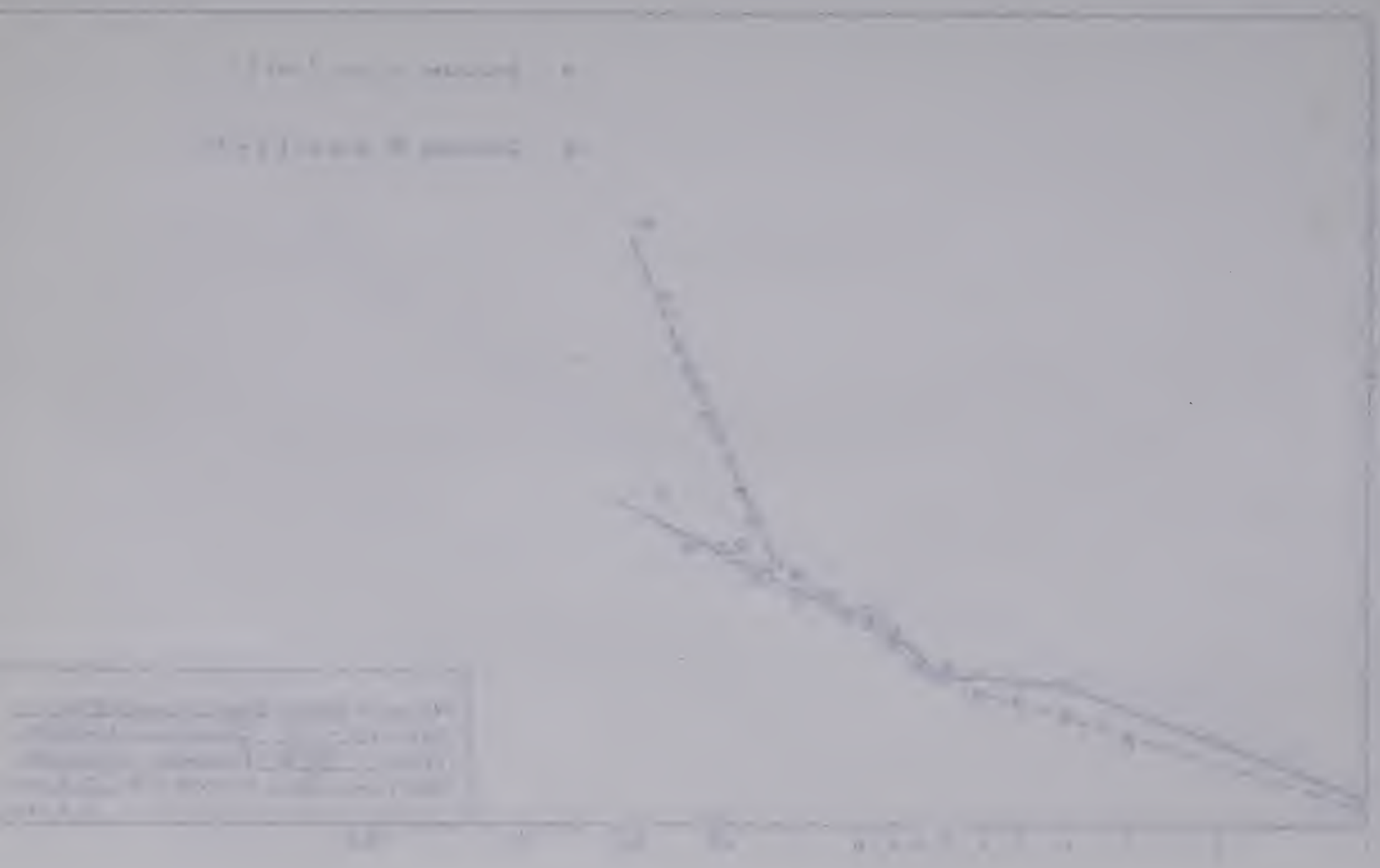


FIGURE: 4 - 24

B. O. D. CURVE "SEMI - LOG"



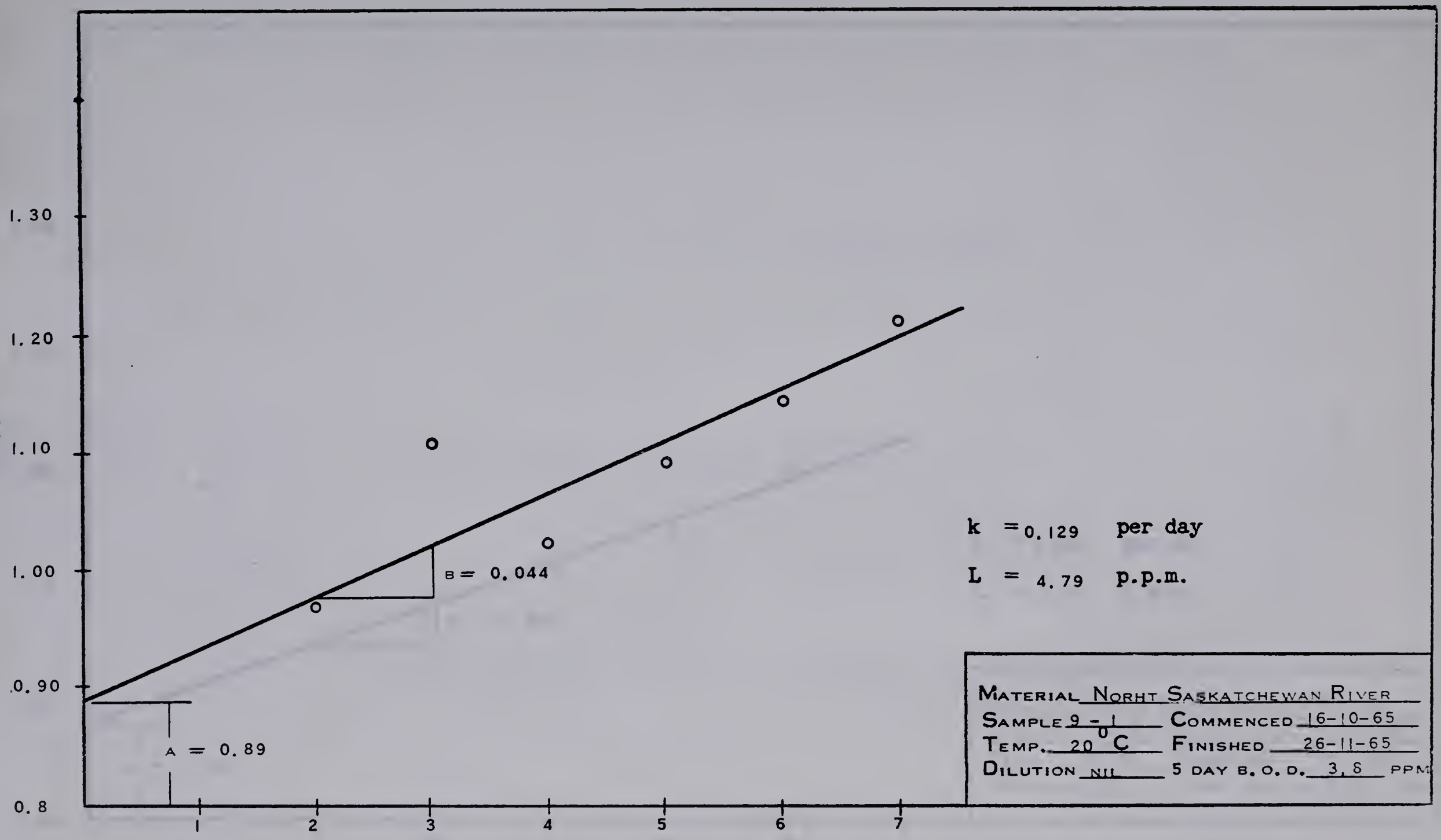
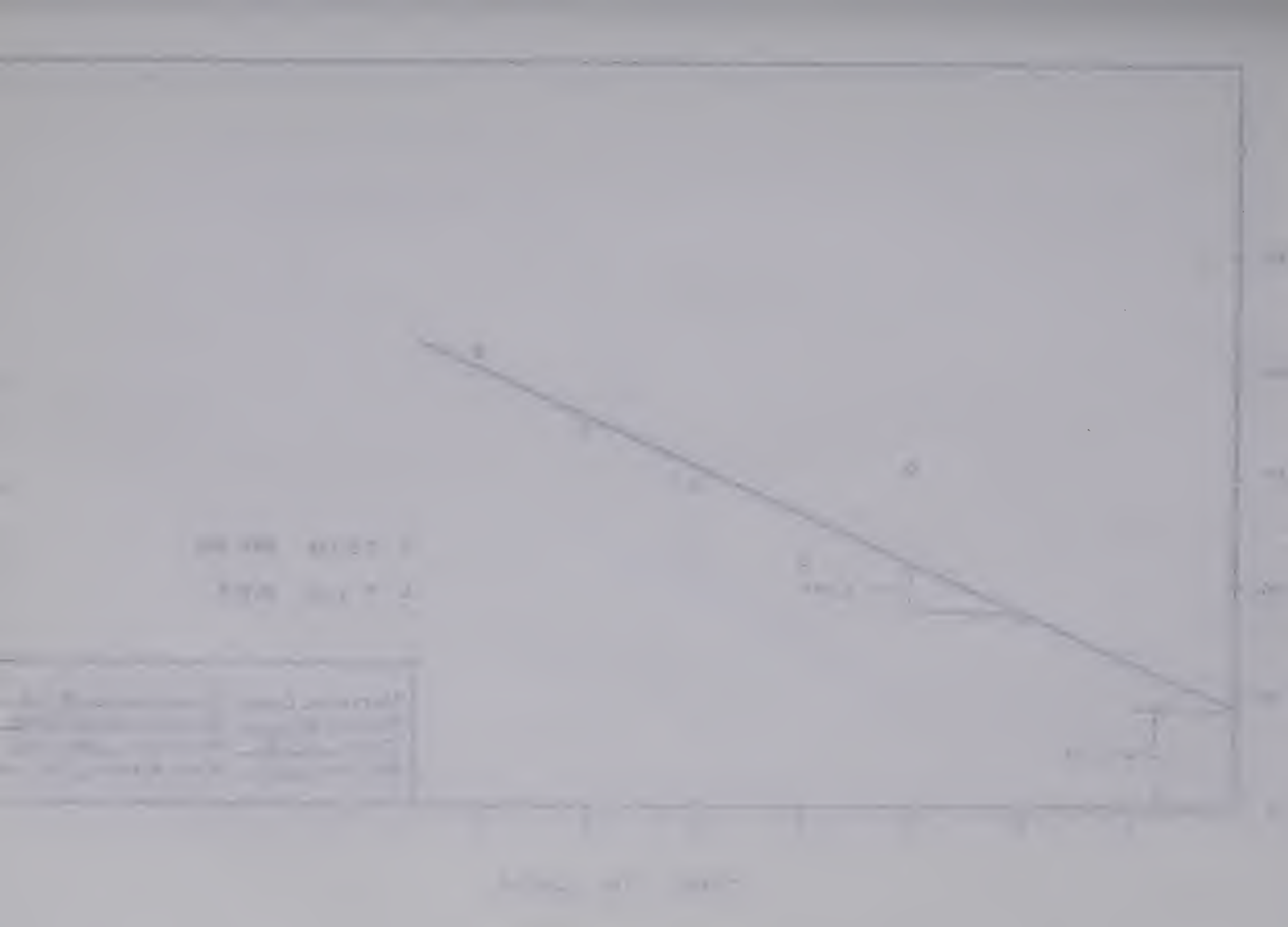


FIGURE: 4 - 25 B.O.D. CURVE CONSTANTS



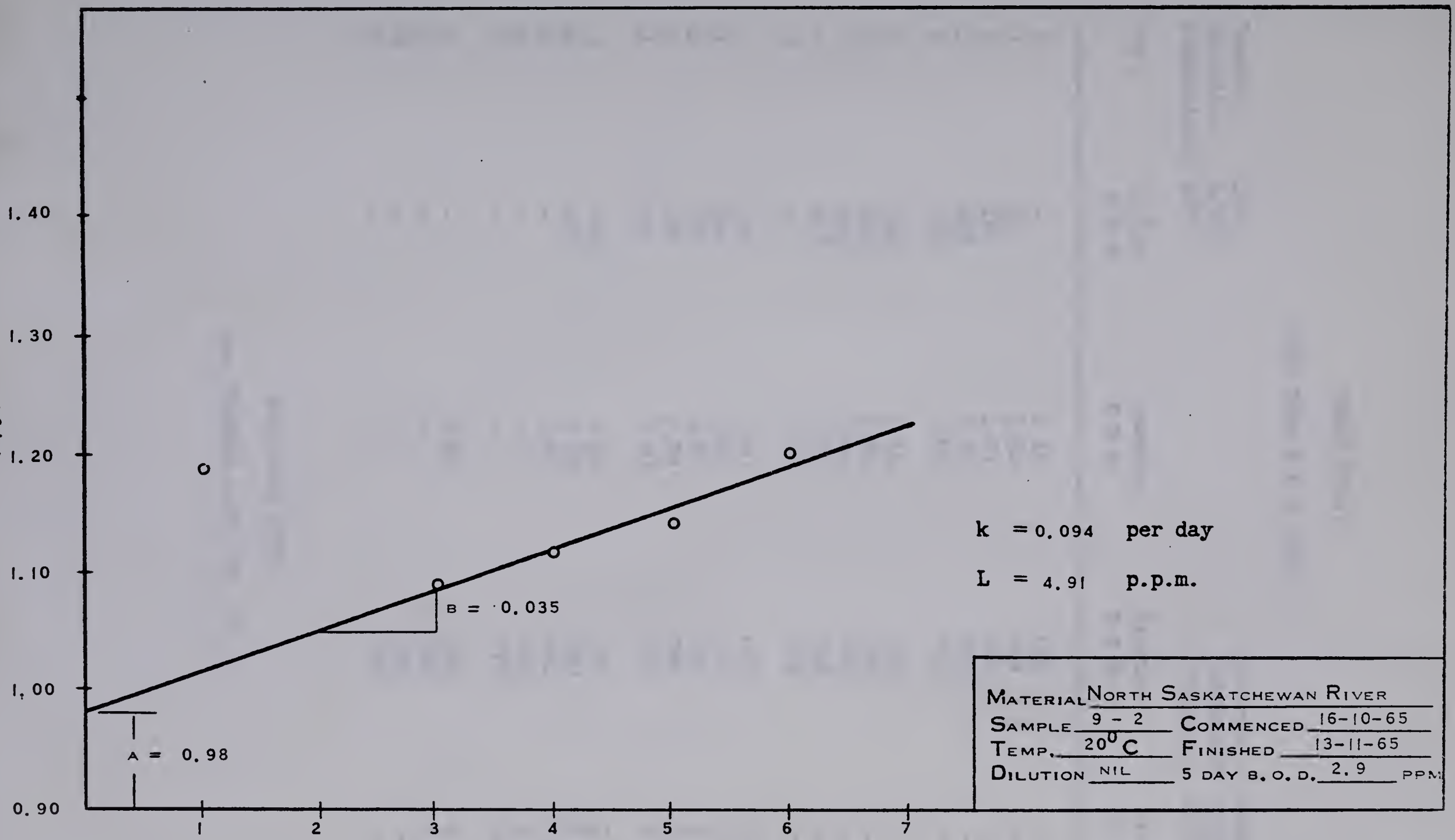


FIGURE: 4 - 26

B. O. D. CURVE CONSTANTS

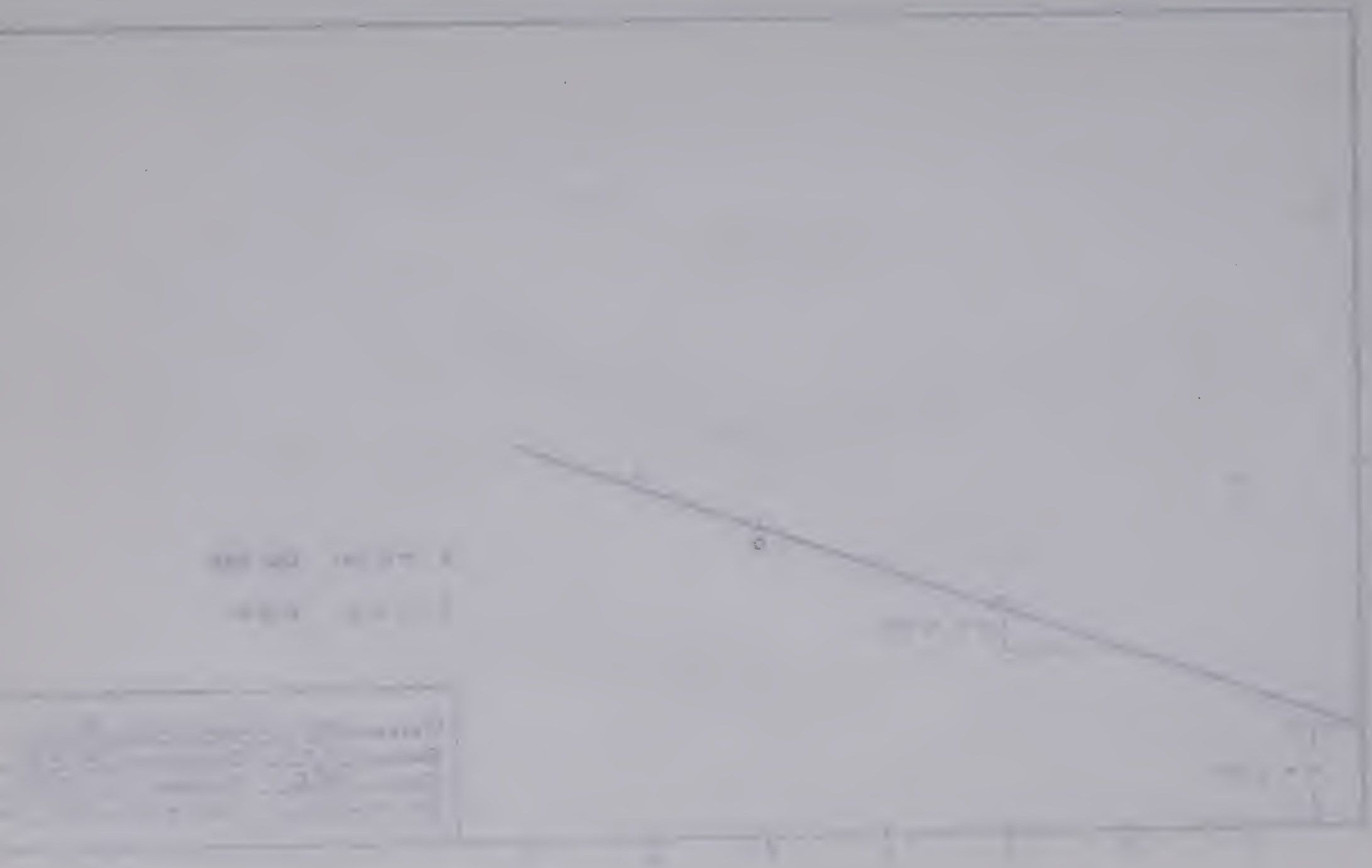


TABLE IV-17

LONG TERM B.O.D. DATA

Sample: 10-1 Material: Sewage
Dilution: 6/300 Commenced: 1/11/65
Temperature: 20°C Finished: 24/11/65

Day	B.O.D. p.p.m.	Ammonia p.p.m.	Nitrite p.p.m.	Nitrate p.p.m.
0	-	1.16	.003	-
1	70	1.00	.003	-
2	112	1.03	.006	-
3	149	0.96	.003	-
4	164	1.00	.003	-
5	182	1.10	.002	-
6	219	1.03	.003	-
7	232	1.06	.005	-
8	247	1.04	.008	-
9	-	1.00	.016	-
10	259	1.00	.027	0.17
11	294	0.96	.070	-
12	295	0.95	.150	0.16
13	297	0.78	.280	0.13
14	364	0.80	.265	0.18
15	422	0.38	.395	0.24
16	472	0.16	.790	0.16
17	-	0.00	.860	0.09
18	-	-	.940	0.62
19	-	-	.970	0.11
20	-	0.00	.950	0.00
21	-	-	.900	0.00
22	-	-	.930	-
23	-	-	.930	-

Incubator Down

See FIGURES 4-27, 28, 29, 53

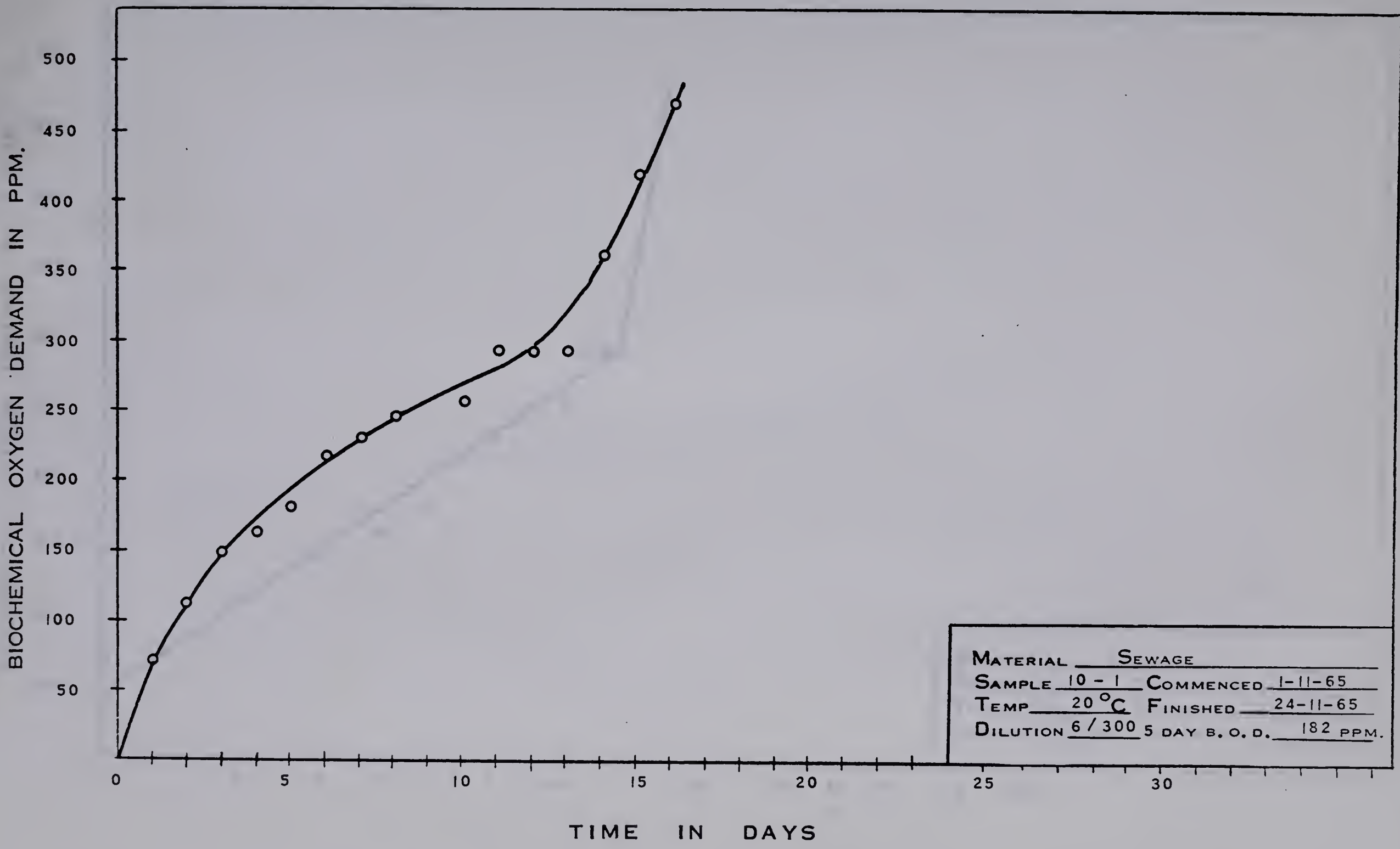


FIGURE: 4 - 27 NORMAL B. O. D. CURVE " ARITHMETIC PLOT "



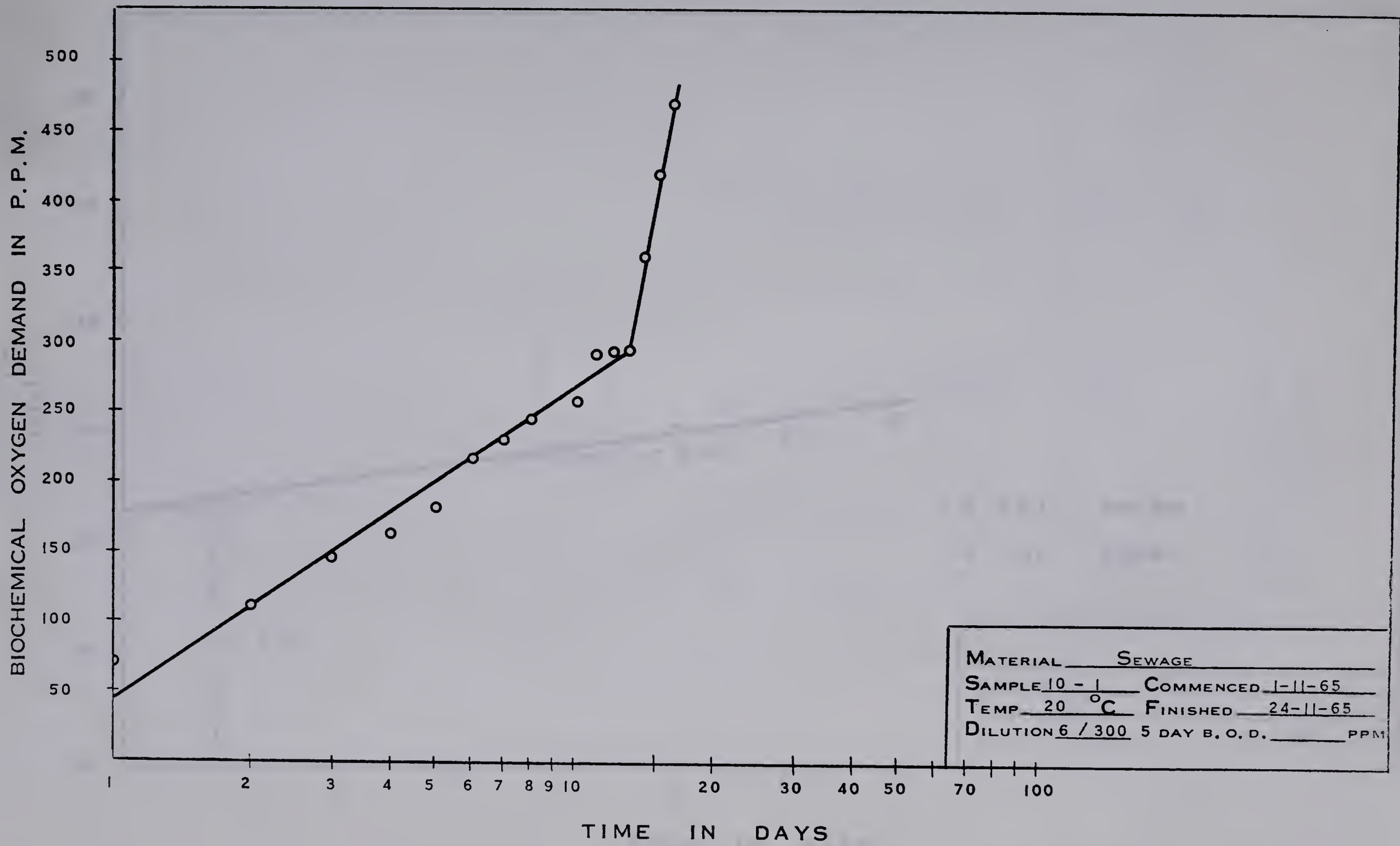


FIGURE: 4 - 28

B. O. D. CURVE "SEMI-LOG"



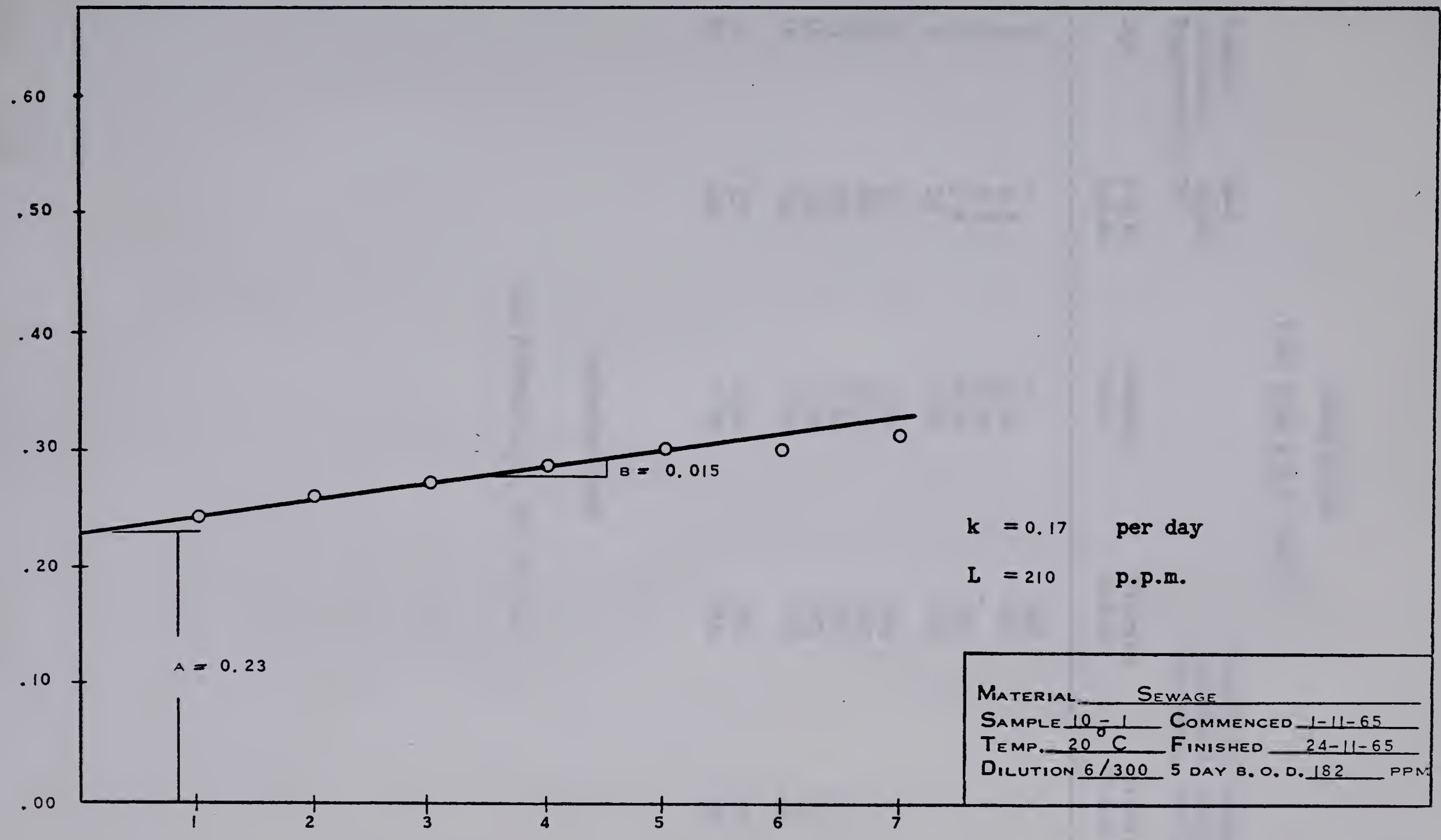


FIGURE 4 - 29 B.O.D. CURVE CONSTANTS

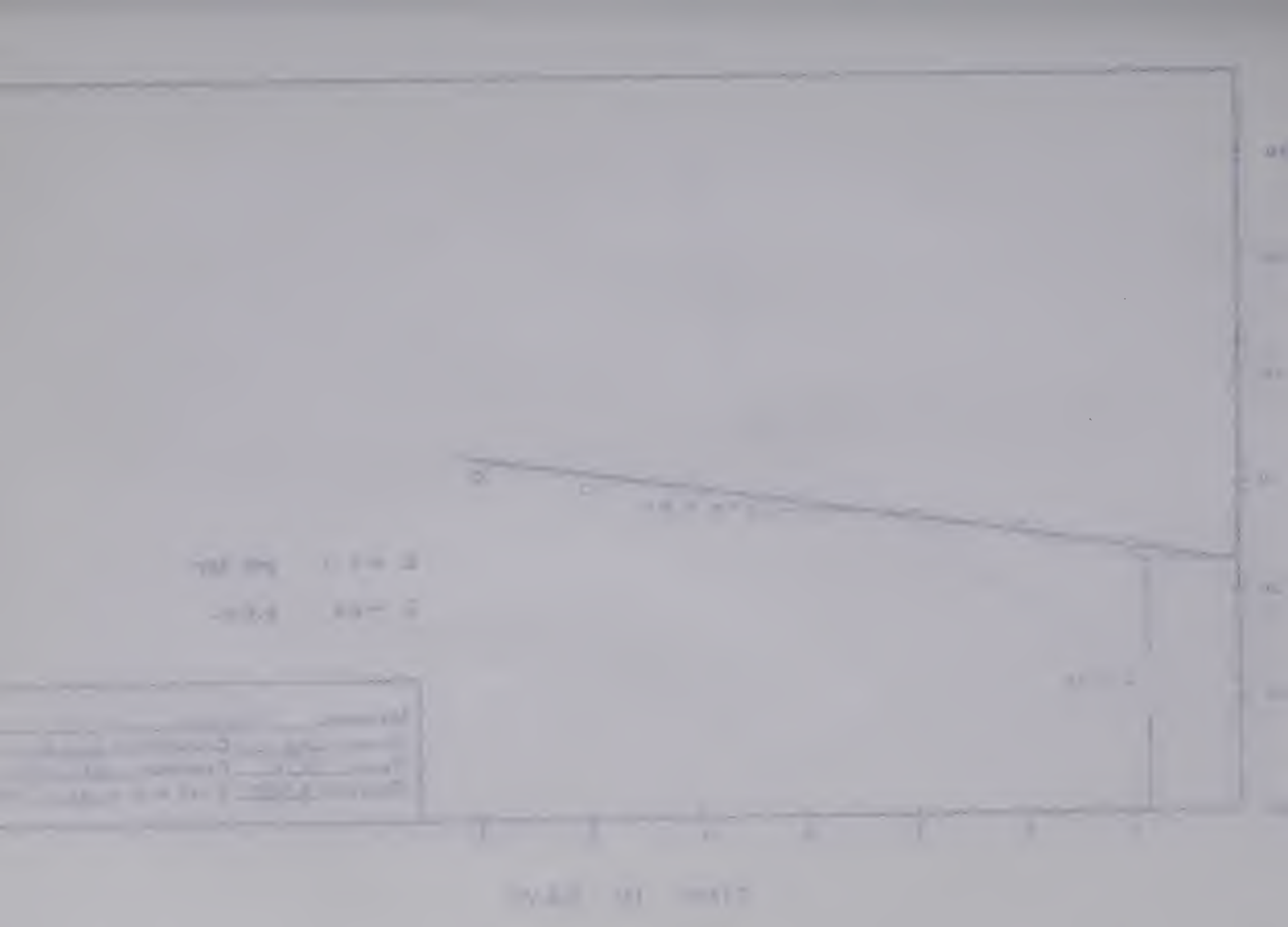


TABLE IV-18

LONG TERM B.O.D. DATA

Sample: 10-2
Dilution: 20/300
Temperature: 0°C

Material: Sewage
Commenced: 1/11/65
Finished: 24/11/65

Day	B.O.D. p.p.m.	Ammonia p.p.m.	Nitrite p.p.m.	Nitrate p.p.m.
0	-	-	.005	-
1	2.3	2.40	.004	-
2	6.8	2.30	-	-
5	3.8	2.50	.003	-
7	15	2.40	.003	-
10	56	2.28	.003	-
12	80	2.22	.005	-
13	90	2.14	.005	-
15	100	2.07	.003	.01
18	114	2.15	.002	.42
21	117	2.20	.002	.00
23	124	2.00	.004	.00

Incubator Down

See FIGURES 4-30, 31, 32, 54

TABLE IV-19

LONG TERM B.O.D. DATA

Sample: 10-3
Dilution: 20/300
Temperature: 2°C

Material: Sewage
Commenced: 1/11/65
Finished: 24/11/65

Day	B.O.D. p.p.m.	Ammonia p.p.m.	Nitrite p.p.m.	Nitrate p.p.m.
0	-	2.13	.004	-
1	3.8	2.13	.003	0.25
2	8	2.14	-	-
5	21	2.13	.003	-
7	64	2.08	.004	-
10	96	1.92	.003	-
12	109	1.91	.004	0.20
13	114	1.88	.003	-
15	118	1.76	.001	0.07
18	124	1.94	.002	-
21	136	1.90	.002	0.00
23	139	1.95	.001	0.00

Incubator Down

See FIGURES 4-30, 31, 33, 54

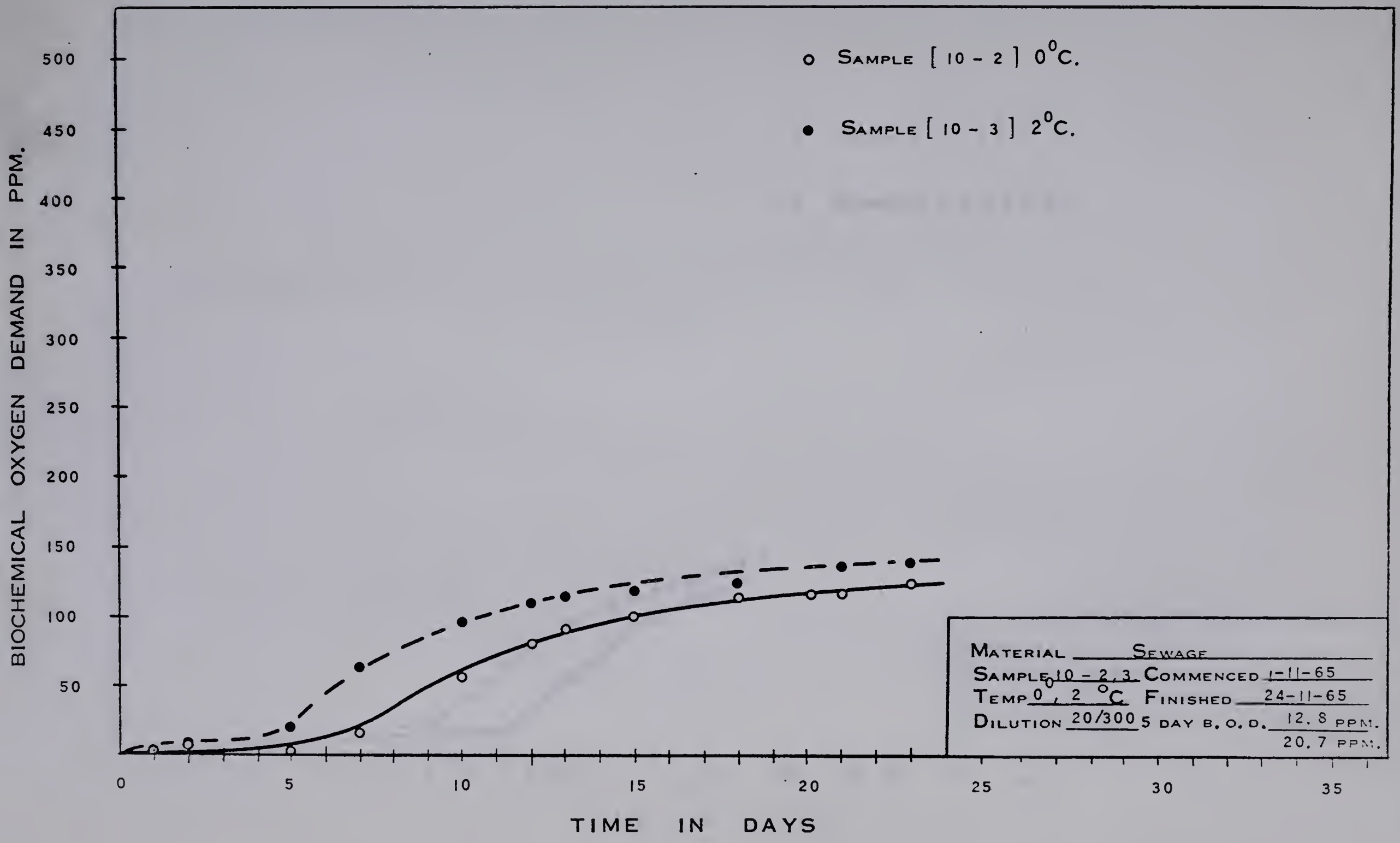
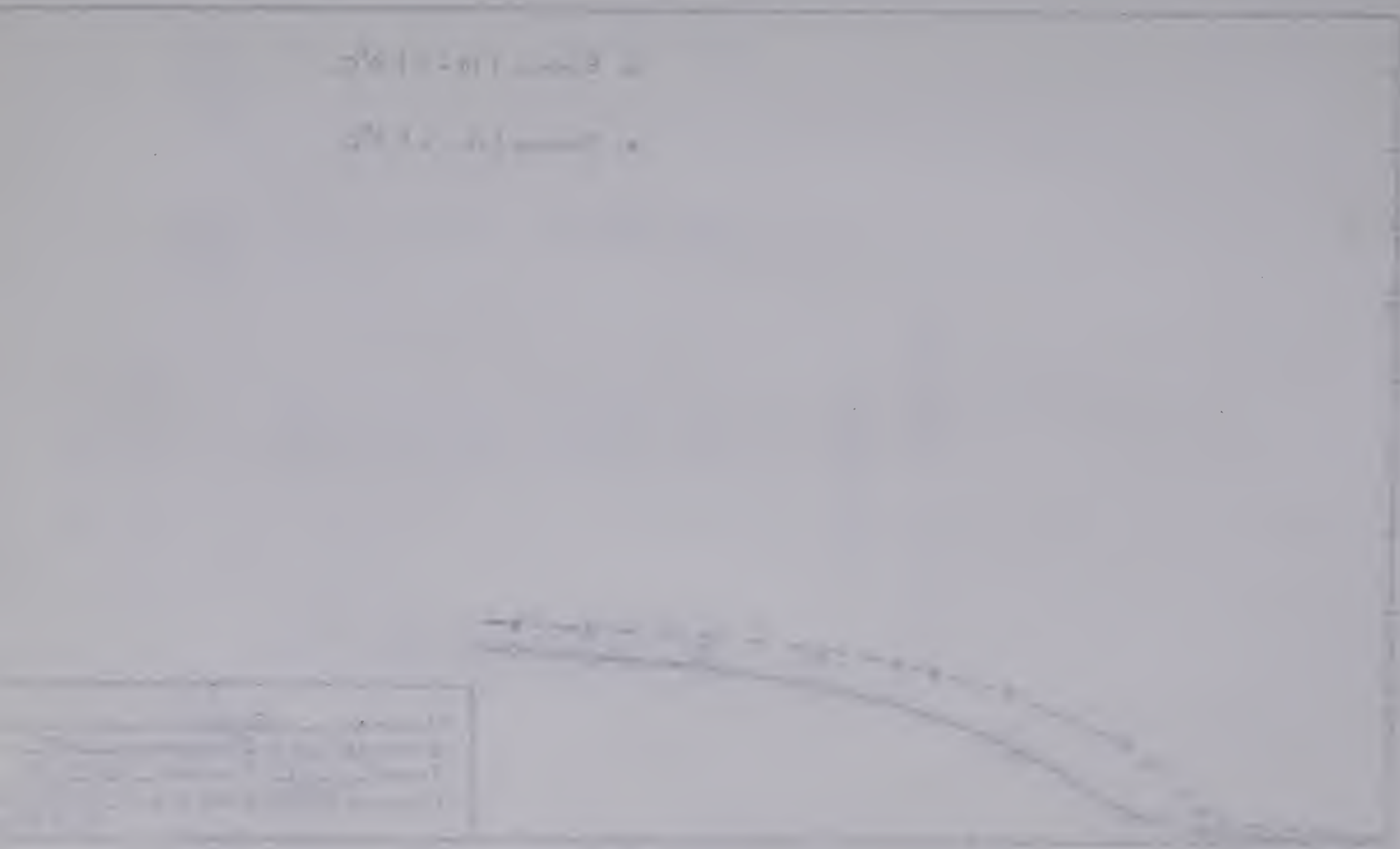


FIGURE: 4 - 30 NORMAL B. O. D. CURVE " ARITHMETIC PLOT "



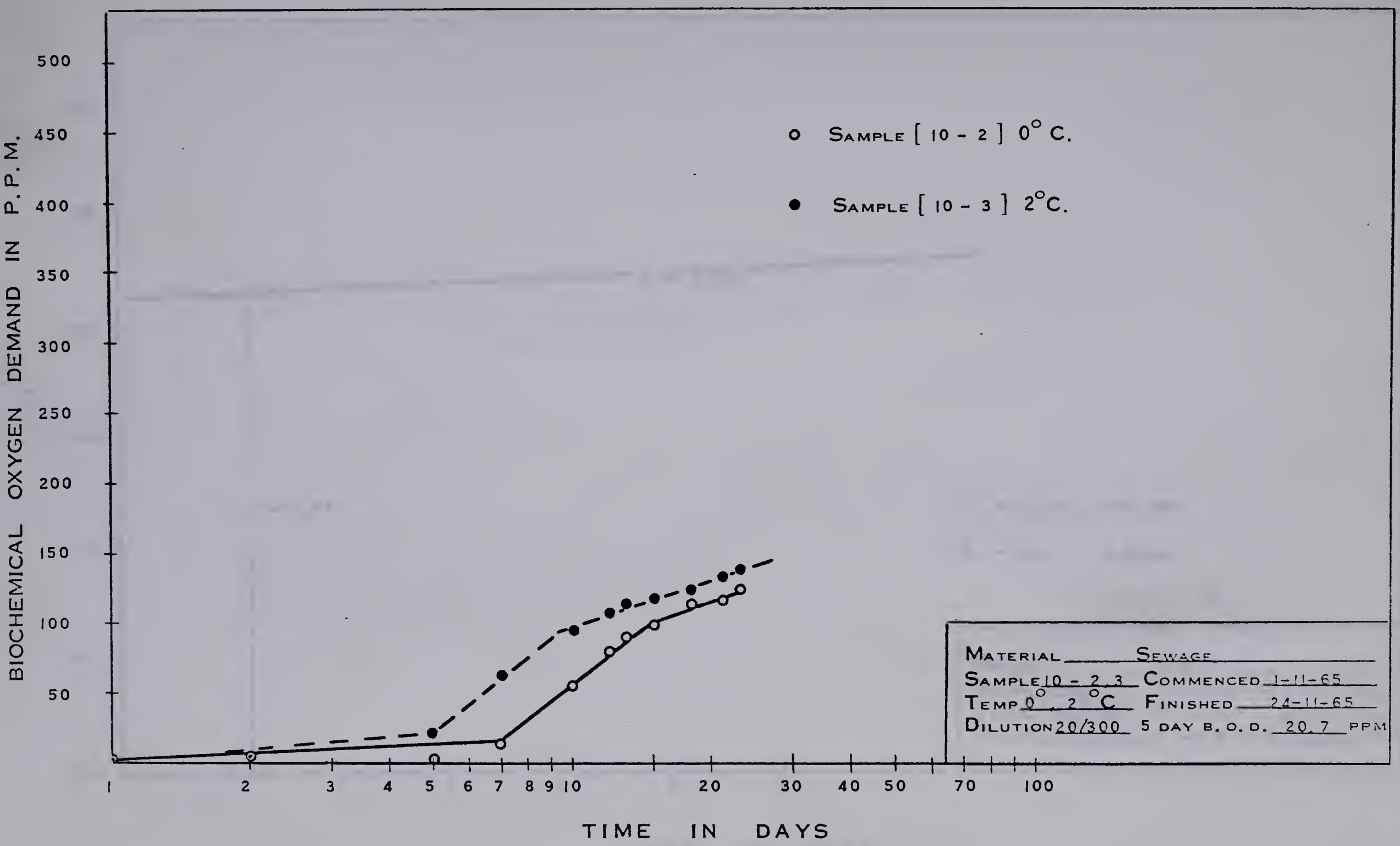
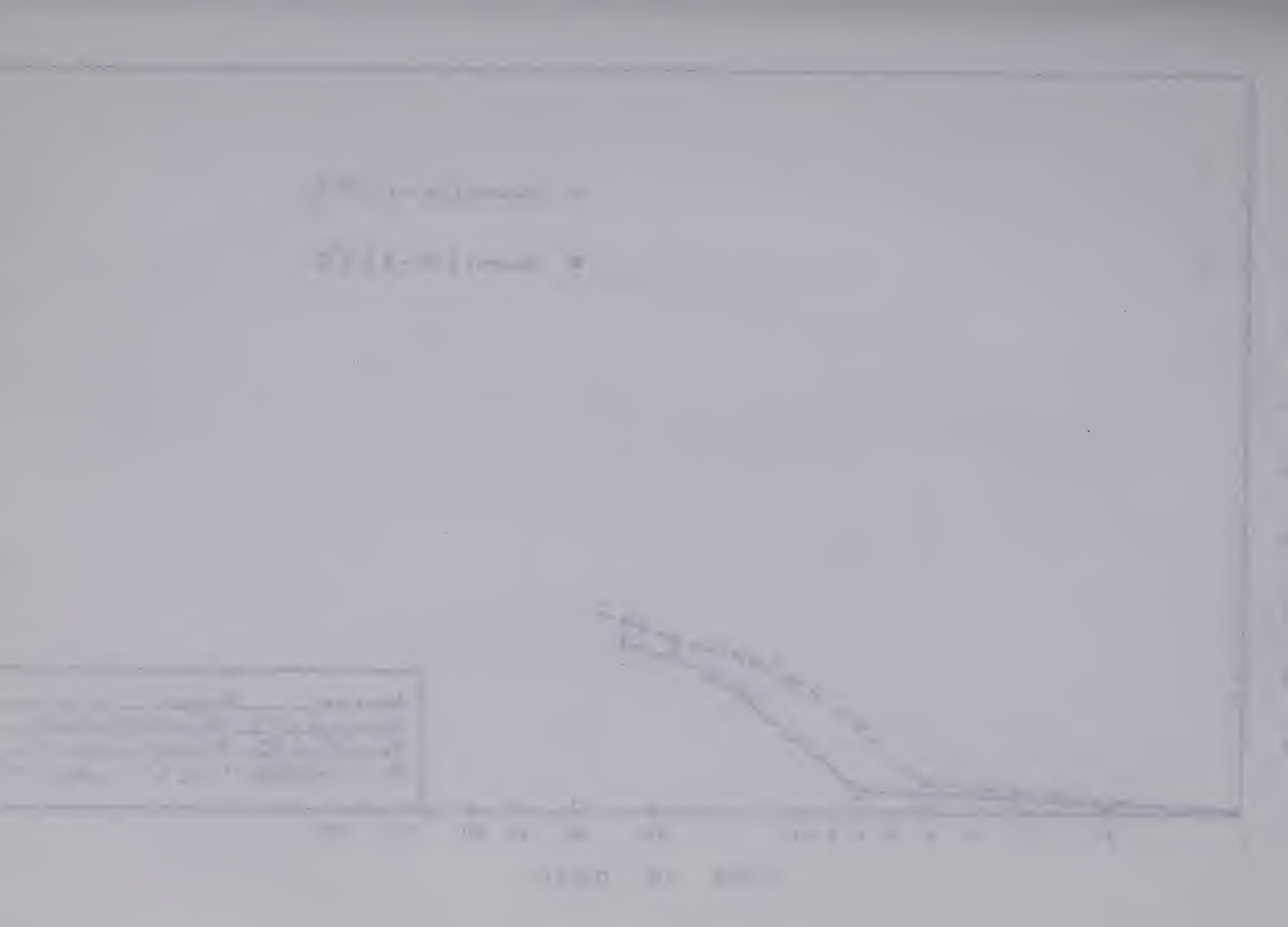
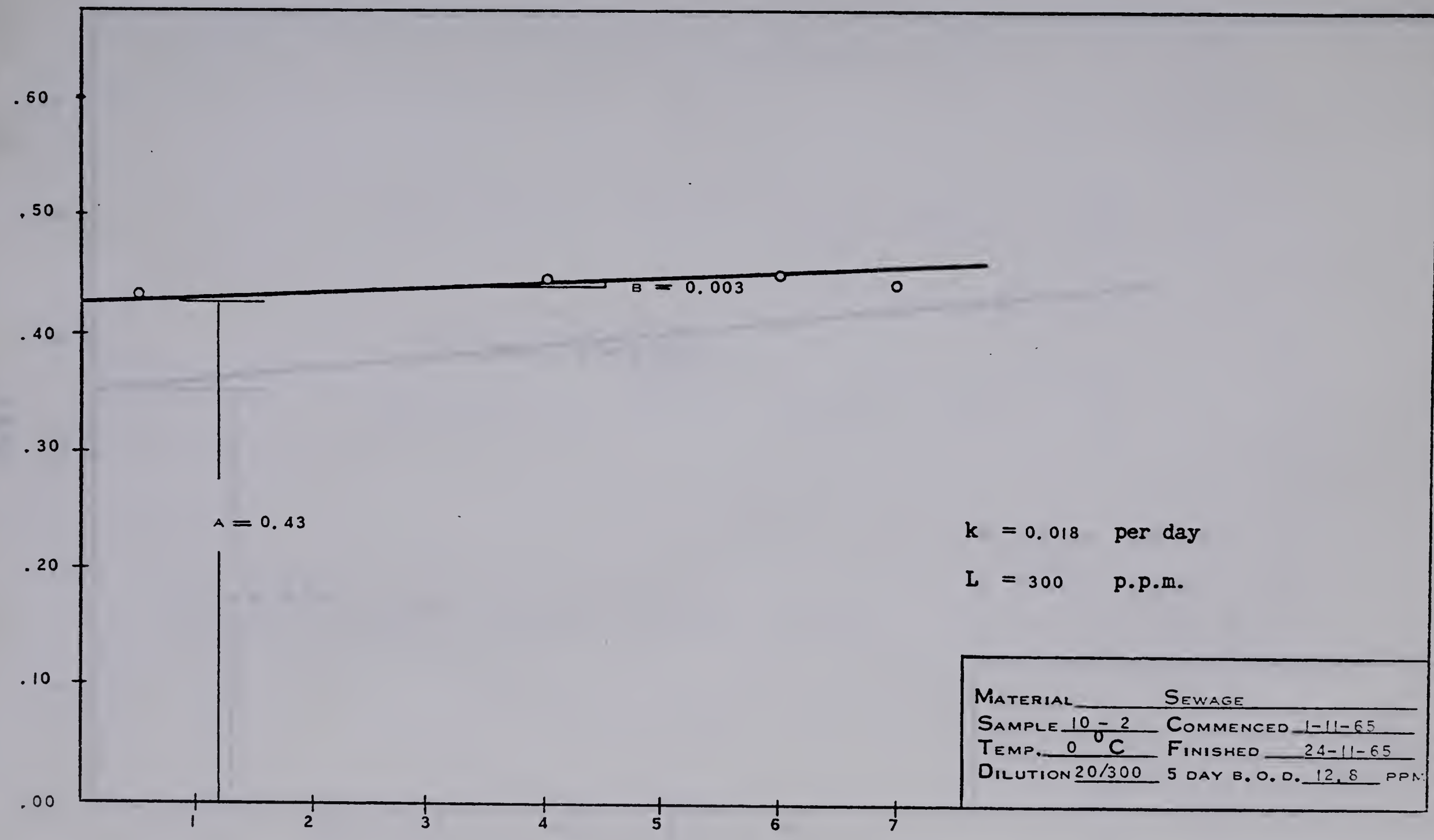


FIGURE: 4 - 31

B. O. D. CURVE "SEMI-LOG"





TIME IN DAYS

FIGURE: 4 - 32 B.O.D. CURVE CONSTANTS



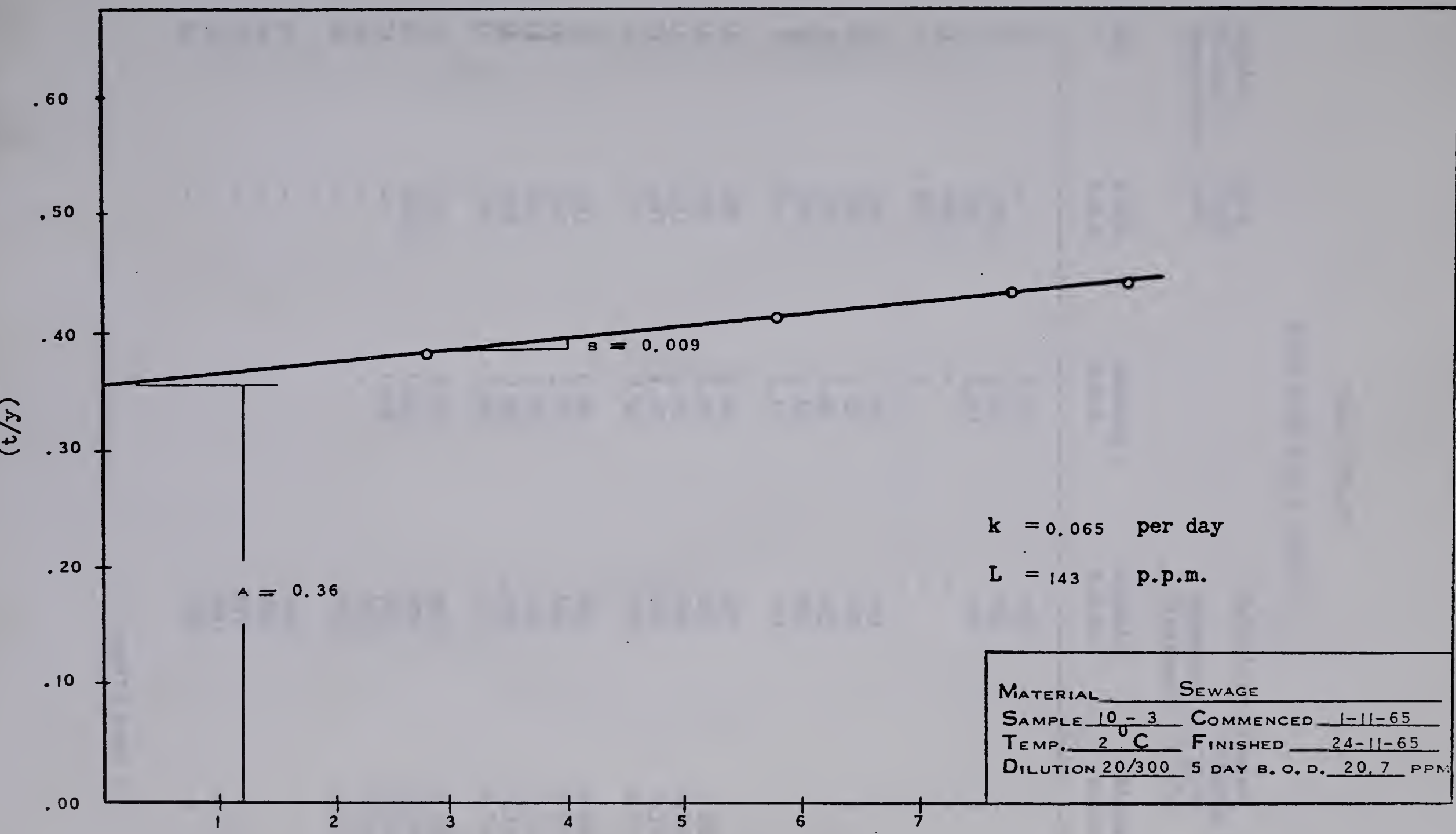


FIGURE: 4 - 33 B.O.D. CURVE CONSTANTS

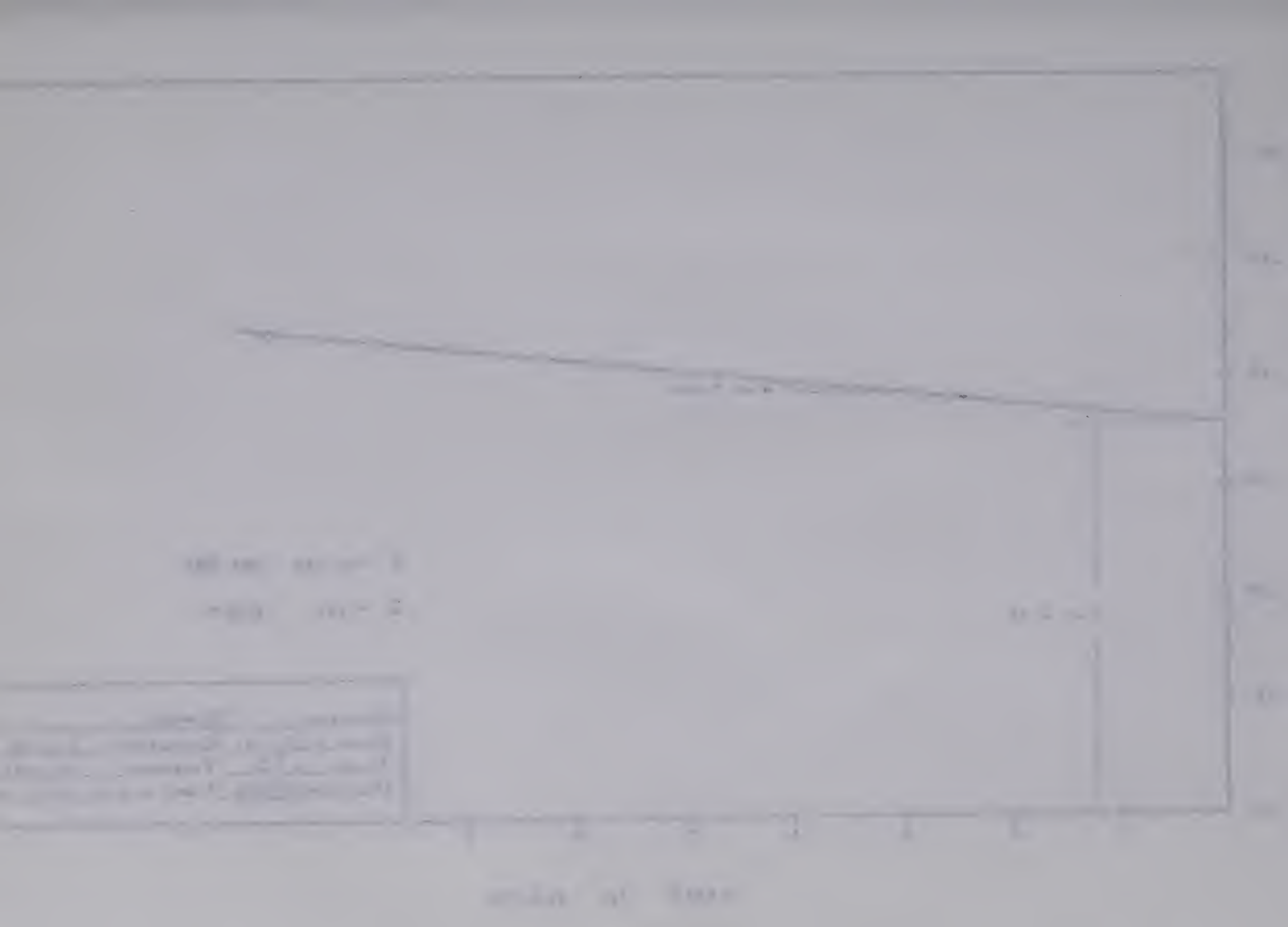


TABLE IV-20

LONG TERM B.O.D. DATA

Sample: 12-2
Dilution: 3/300
Temperature: 20°C

Material: Sewage, Cylinder A
Commenced: 5/12/65
Finished: 13/1/66

Day	B.O.D. p.p.m.	Ammonia p.p.m.	Nitrite p.p.m.	Nitrate p.p.m.
0	-	1.29	.003	-
1	100	1.18	.002	-
2	127	1.20	.002	-
3	200	-	-	-
4	240	-	-	-
5	286	1.28	.003	-
6	326	1.18	.002	-
7	307	1.22	.003	-
8	367	1.12	.001	-
9	387	1.12	.003	-
10	407	1.04	.003	-
11	433	1.04	.005	0.21
12	453	1.08	.010	0.18
13	487	1.00	.014	0.36
14	500	0.98	.026	0.09
15	553	0.98	.057	0.06
16	587	1.00	.104	0.00
17	660	0.86	.113	0.13
18	709	0.80	.350	0.33
19	793	0.52	.475	0.19
20	953	0.20	.800	0.00
21	1033	0.12	.876	0.00
23	-	0.00	.925	0.00
25	-	-	.875	0.26
26	-	-	.980	0.36
27	-	-	.870	-
28	-	-	.900	-
29	-	-	.870	-
30	-	-	.800	0.00
31	-	-	.750	-

.....cont'd page 97

TABLE IV-20 continued from page 96

Day	B.O.D. p.p.m.	Ammonia p.p.m.	Nitrite p.p.m.	Nitrate p.p.m.
32	-	-	.810	-
33	-	-	.810	-
34	-	-	.480	0.23
35	-	-	.450	-
36	-	-	.150	-
37	-	-	.140	-
38	-	-	.090	0.23
39	1560	-	.001	-

See FIGURES 4-34, 35, 36, 55

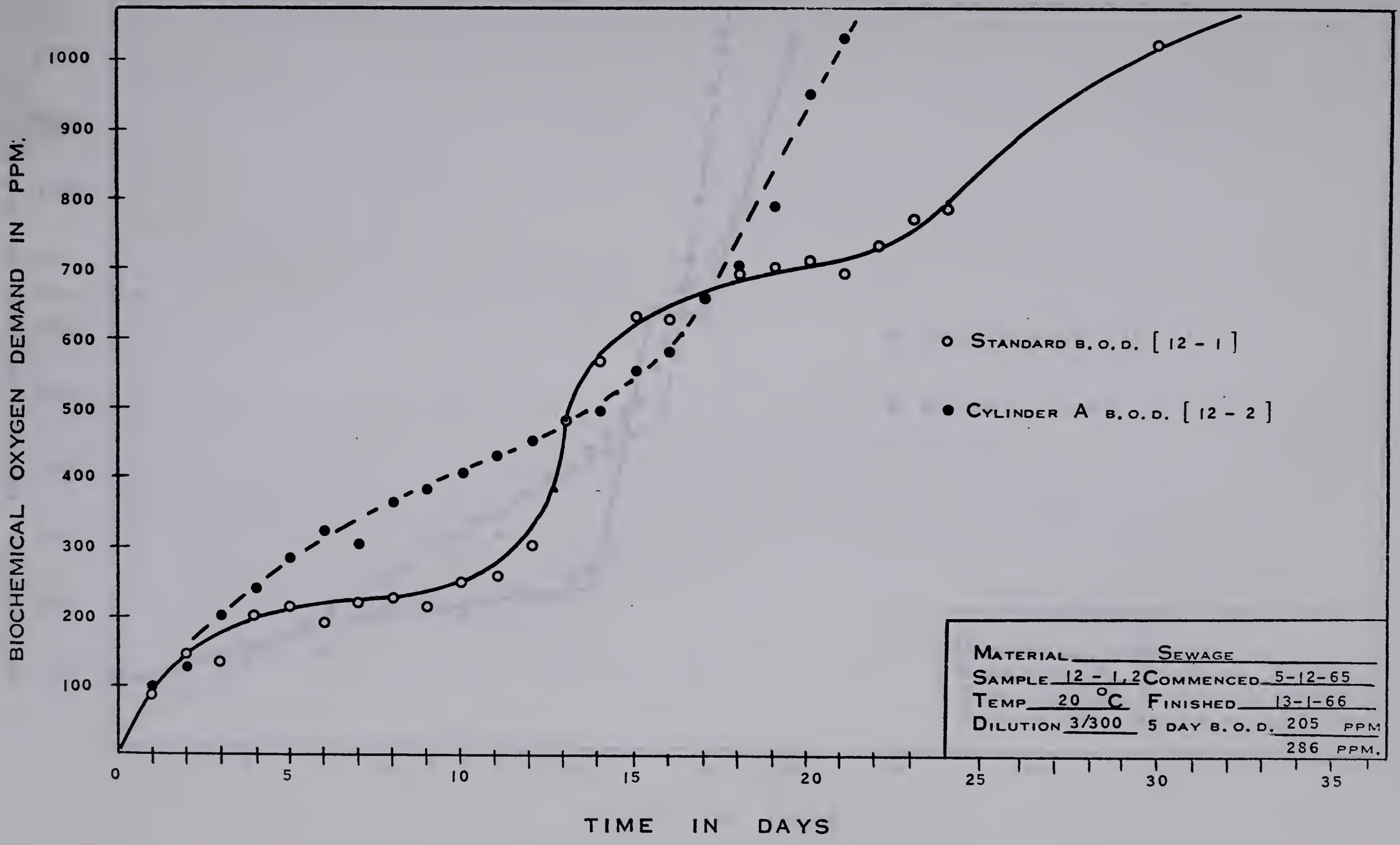
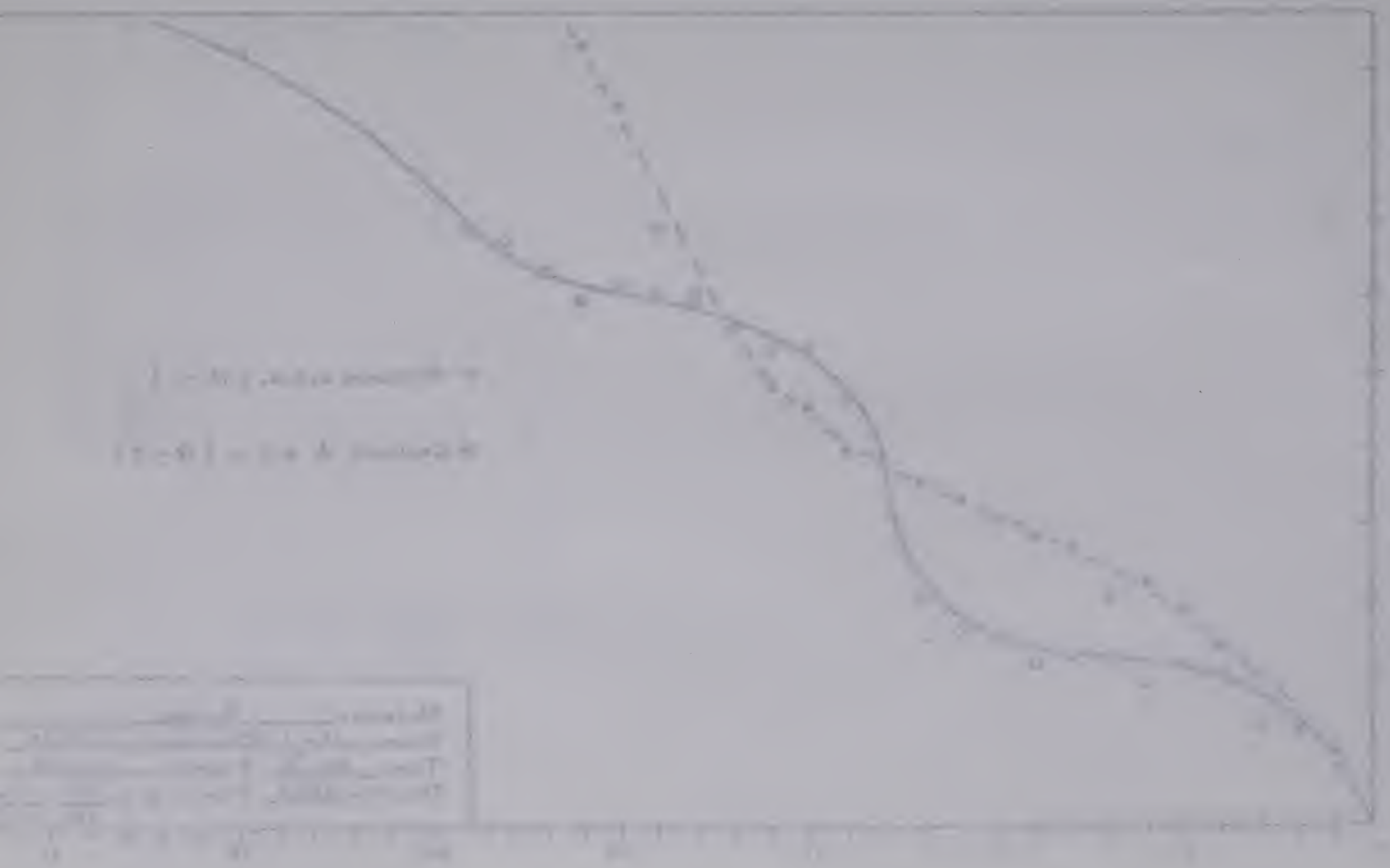


FIGURE: 4 - 34 NORMAL B.O.D. CURVE " ARITHMETIC PLOT"



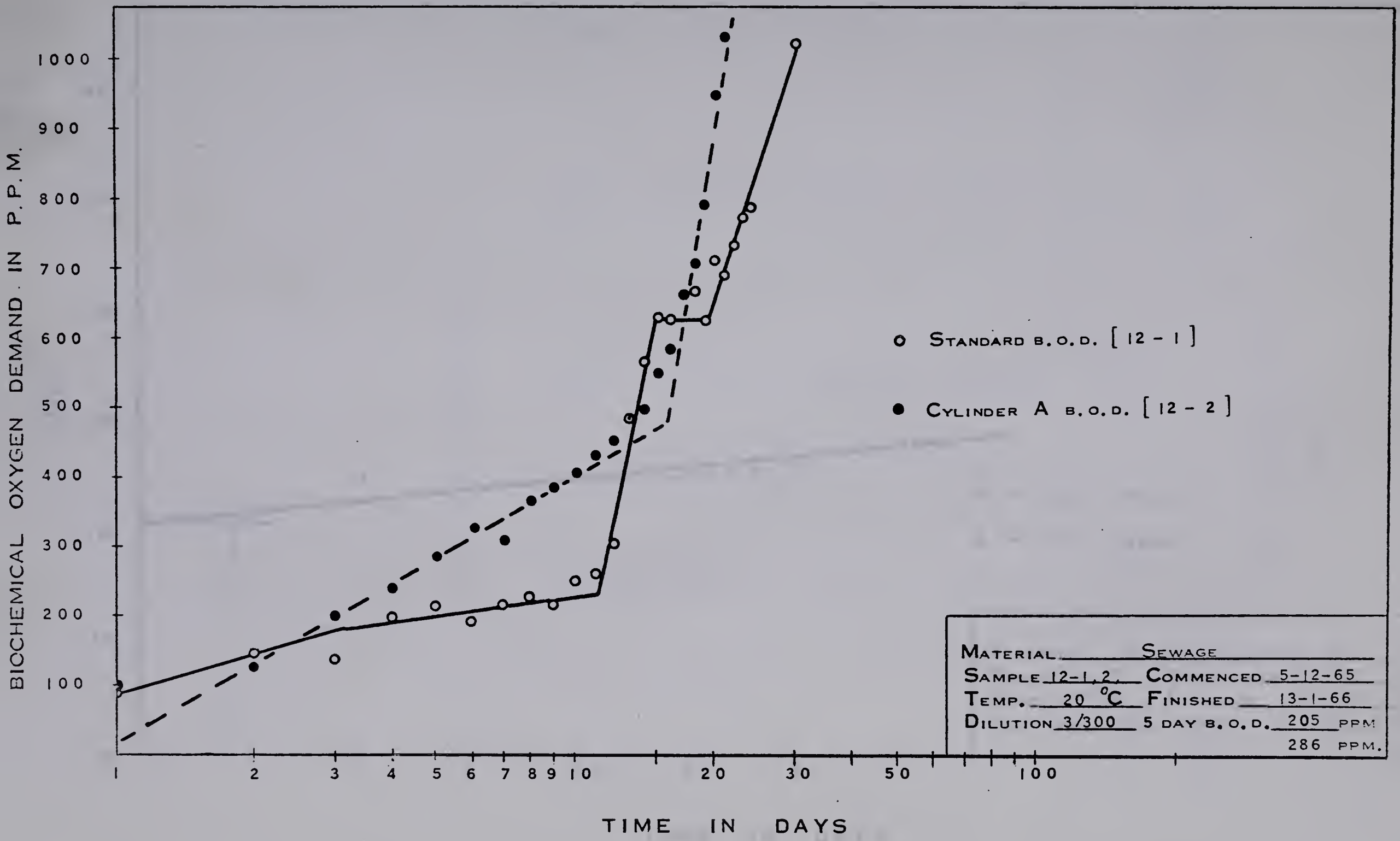
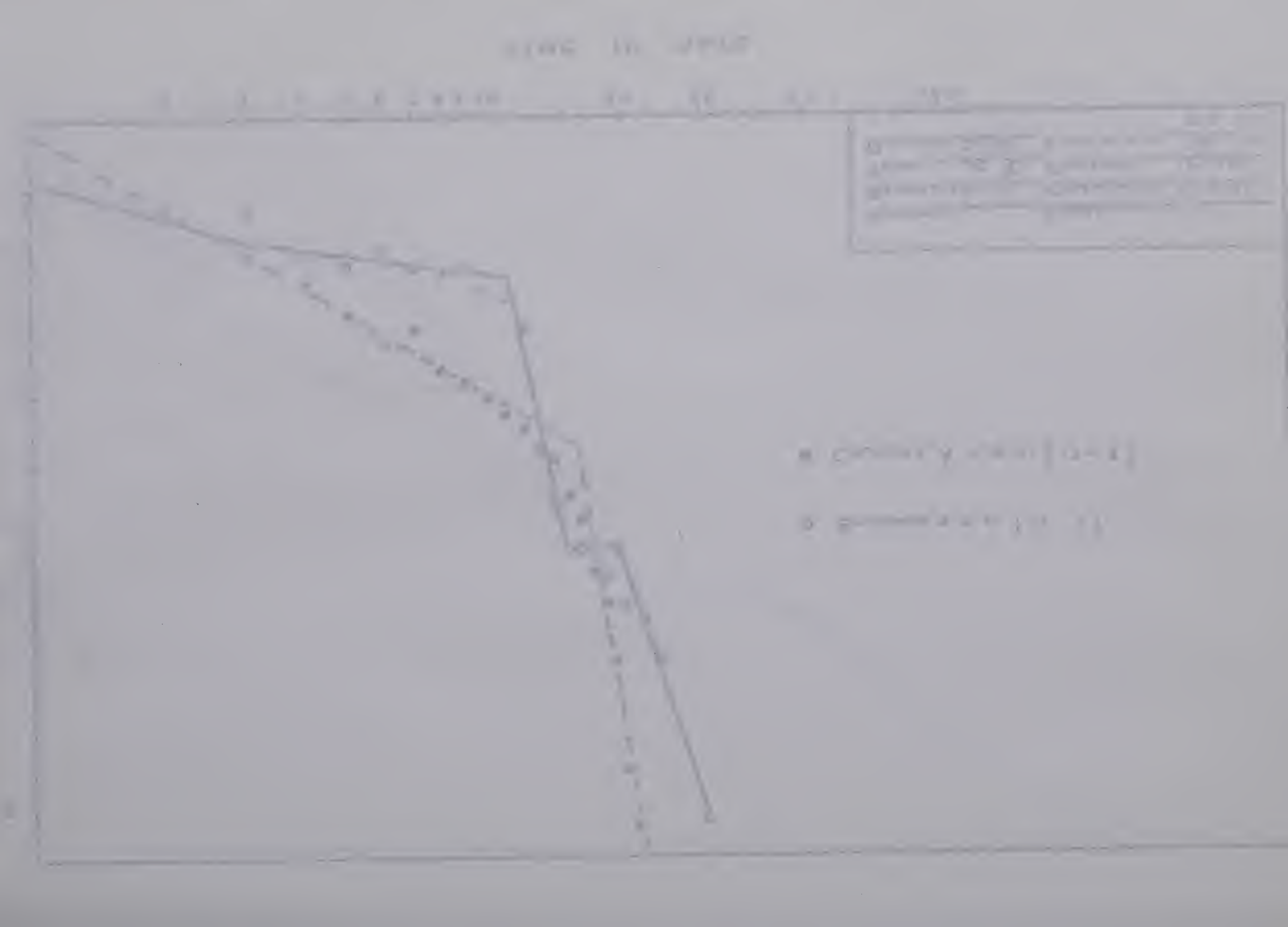


FIGURE: 4- 35

B. O. D. CURVE "SEMI - LOG"



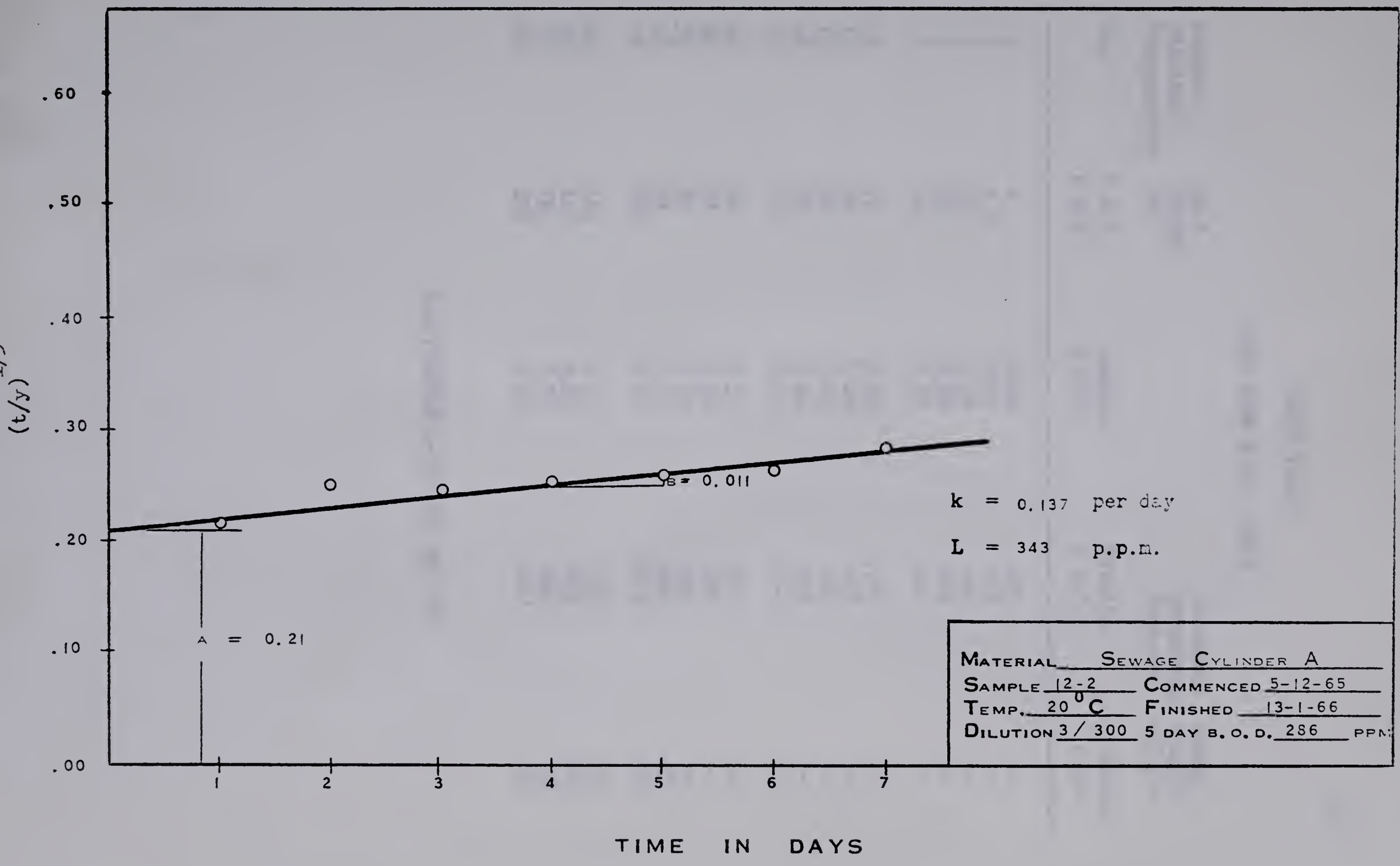


FIGURE: 4 - 36

B. O. D. CURVE CONSTANTS

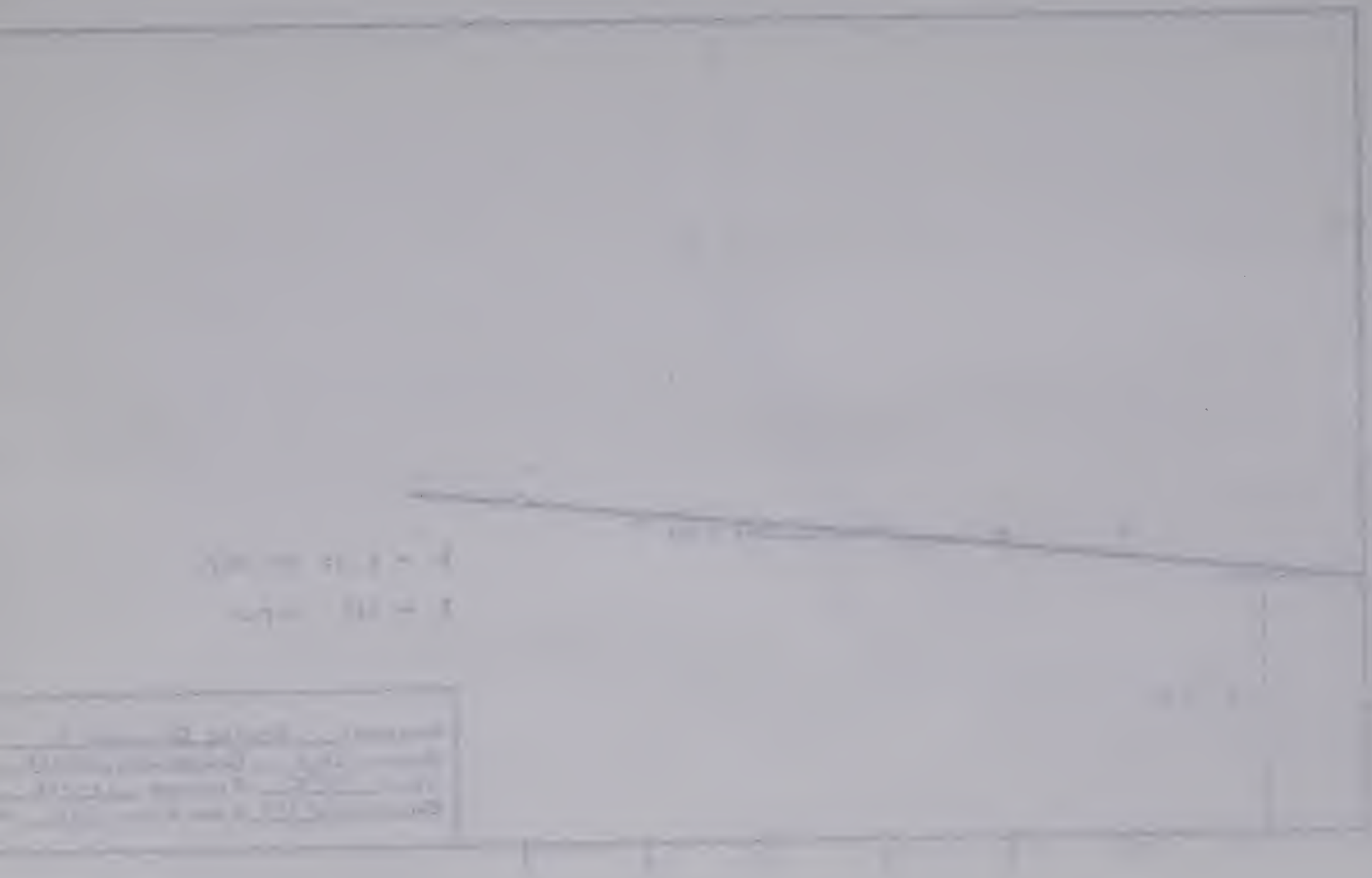


TABLE IV-21

LONG TERM B.O.D. DATA

Sample: 12-5
Dilution: 20/300
Temperature: 0°C

Material: Sewage
Commenced: 5/12/65
Finished: 26/2/66

Day	B.O.D. p.p.m.	Ammonia p.p.m.	Nitrite p.p.m.	Nitrate p.p.m.
0	-	2.40	.003	-
2	6.8	2.22	.002	-
5	19	2.40	.002	-
7	30	2.29	.003	-
9	40	2.15	.003	-
11	47	2.00	.002	-
13	49	2.00	.001	-
15	60	2.08	.002	-
18	69	2.14	.003	-
21	65	2.40	.002	-
24	74	2.14	.002	-
28	77	2.40	.002	-
34	83	2.15	.002	-
40	83	2.32	.002	.09
46	100	2.14	.003	.06
54	112	2.30	.002	.00
60	110	2.30	.003	.10
70	134	2.35	.004	.00
83	128	2.15	.002	.00

See FIGURES 4-37, 38, 39, 56

TABLE IV-22

LONG TERM B.O.D. DATA

Sample: 12-6
Dilution: 15/300
Temperature: 2°C

Material: Sewage
Commenced: 5/12/65
Finished: 26/2/66

Day	B.O.D. p.p.m.	Ammonia p.p.m.	Nitrite p.p.m.	Nitrate p.p.m.
0	-	2.11	.003	-
2	7	1.89	.002	-
5	23	1.94	.002	-
7	38	1.88	.002	-
9	47	1.88	.002	-
11	52	1.72	.002	-
13	56	1.77	.002	-
15	61	1.77	.002	-
18	64	1.84	.002	-
21	65	1.82	.002	-
24	70	1.94	.002	-
28	73	2.08	.002	-
34	81	1.80	.001	-
40	85	1.94	.002	.17
46	102	1.88	.003	.00
54	108	2.00	.002	.31
60	115	1.97	.002	.22
70	113	2.00	.002	.00
83	130	1.82	.001	.00

See FIGURES 4-37, 38, 40, 56

TABLE IV-23

LONG TERM B.O.D. DATA

Sample: 12-7
Dilution: 10/300
Temperature: 5°C

Material: Sewage
Commenced: 5/12/65
Finished: 26/2/66

Day	B.O.D. p.p.m.	Ammonia p.p.m.	Nitrite p.p.m.	Nitrate p.p.m.
0	-	1.61	.003	.50
2	21	1.50	.001	.08
5	35	1.58	.002	-
7	63	1.48	.002	.11
9	63	1.46	.002	.02
11	75	1.46	.003	.25
13	71	1.46	.002	.65
15	76	1.44	.002	.12
18	90	1.52	.002	.52
21	42	1.56	.002	.24
24	99	1.52	.003	.14
28	108	1.76	.002	.16
34	120	1.52	.002	.36
40	126	1.64	.003	.11
46	136	1.48	.004	.00
54	168	1.66	.007	.00
60	187	1.56	.017	.23
70	218	1.58	.083	.00
83	344	1.16	.250	.07

See FIGURES 4-37, 38, 41, 56

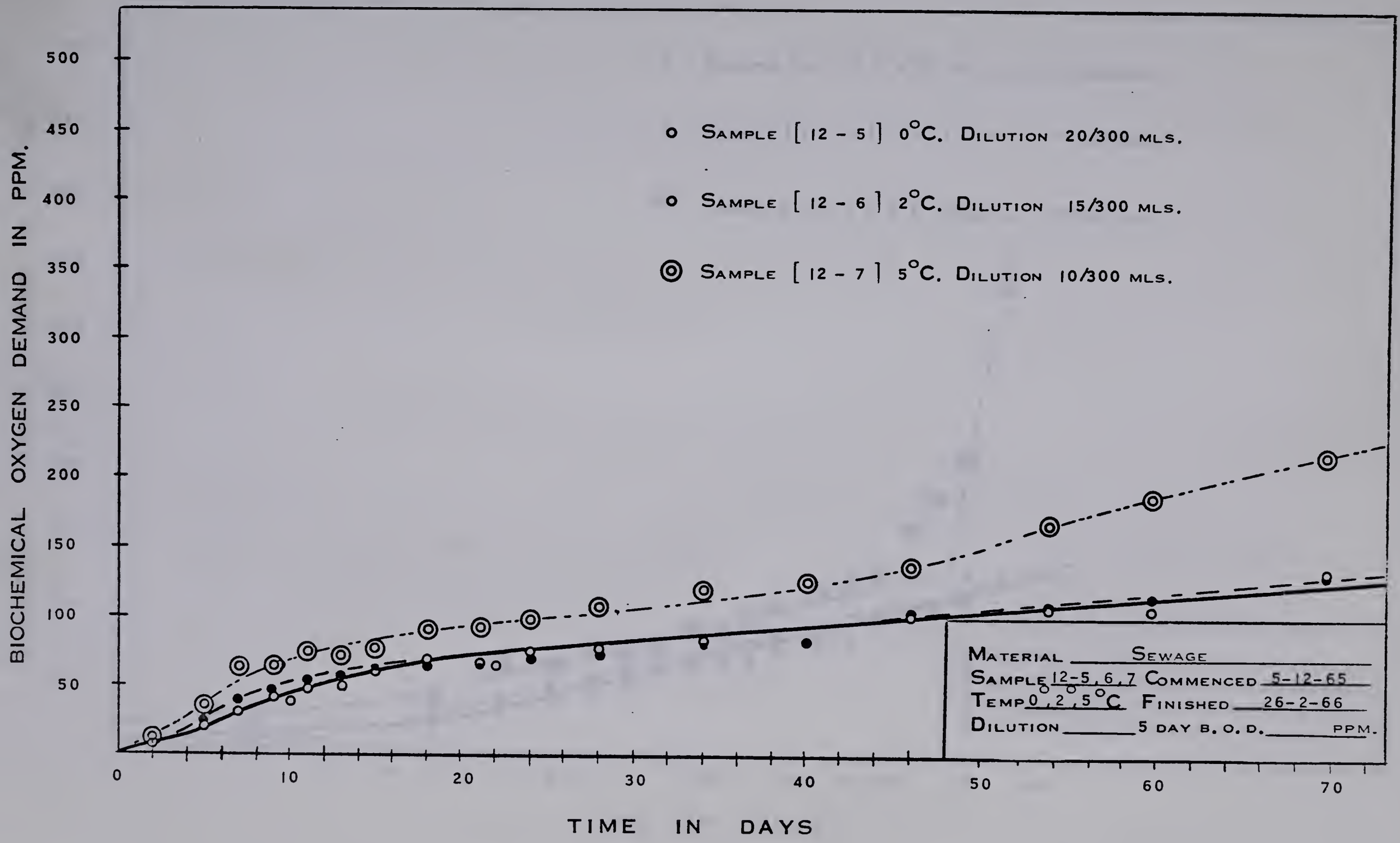
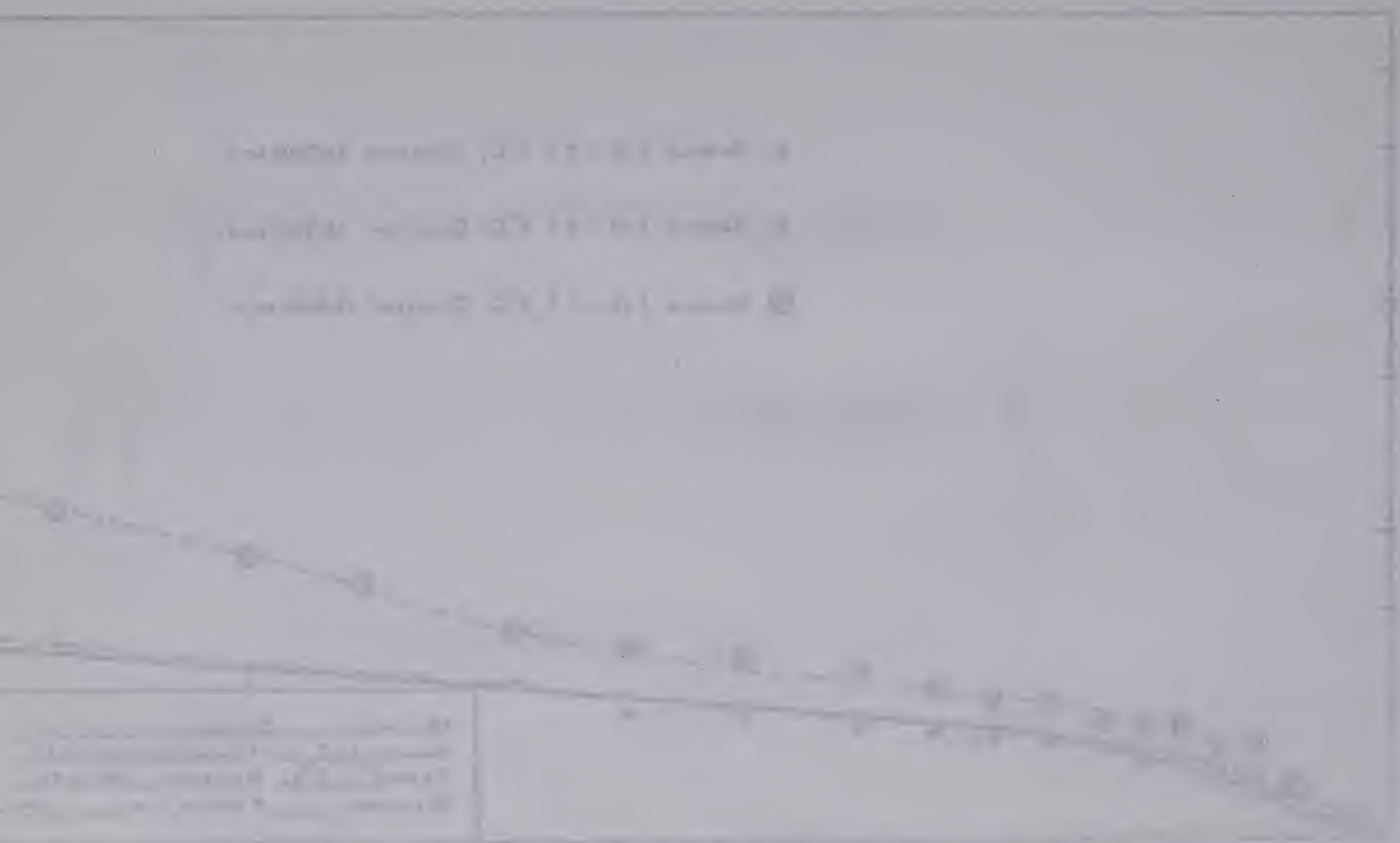


FIGURE: 4 - 37 NORMAL B. O. D. CURVE " ARITHMETIC PLOT "



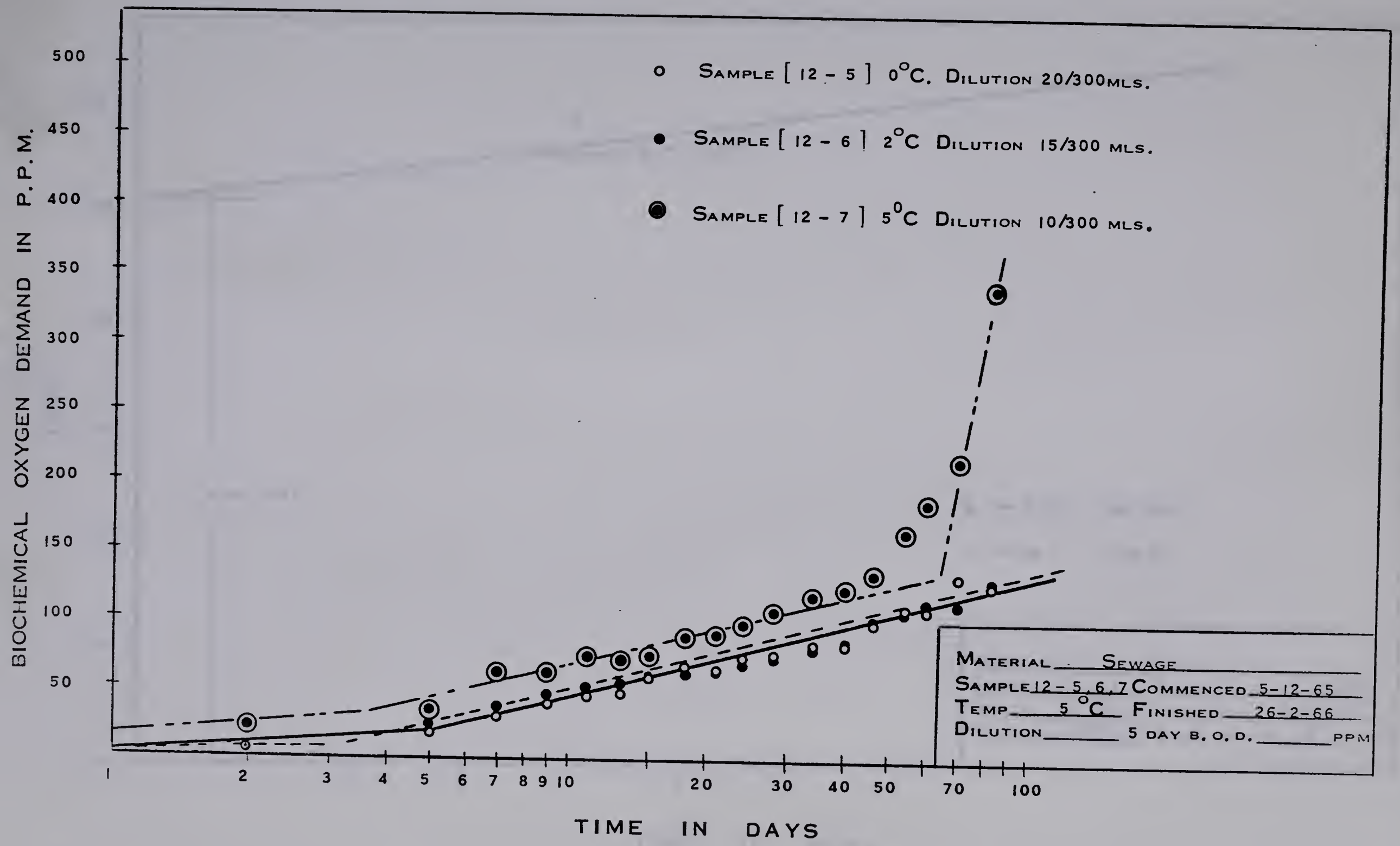
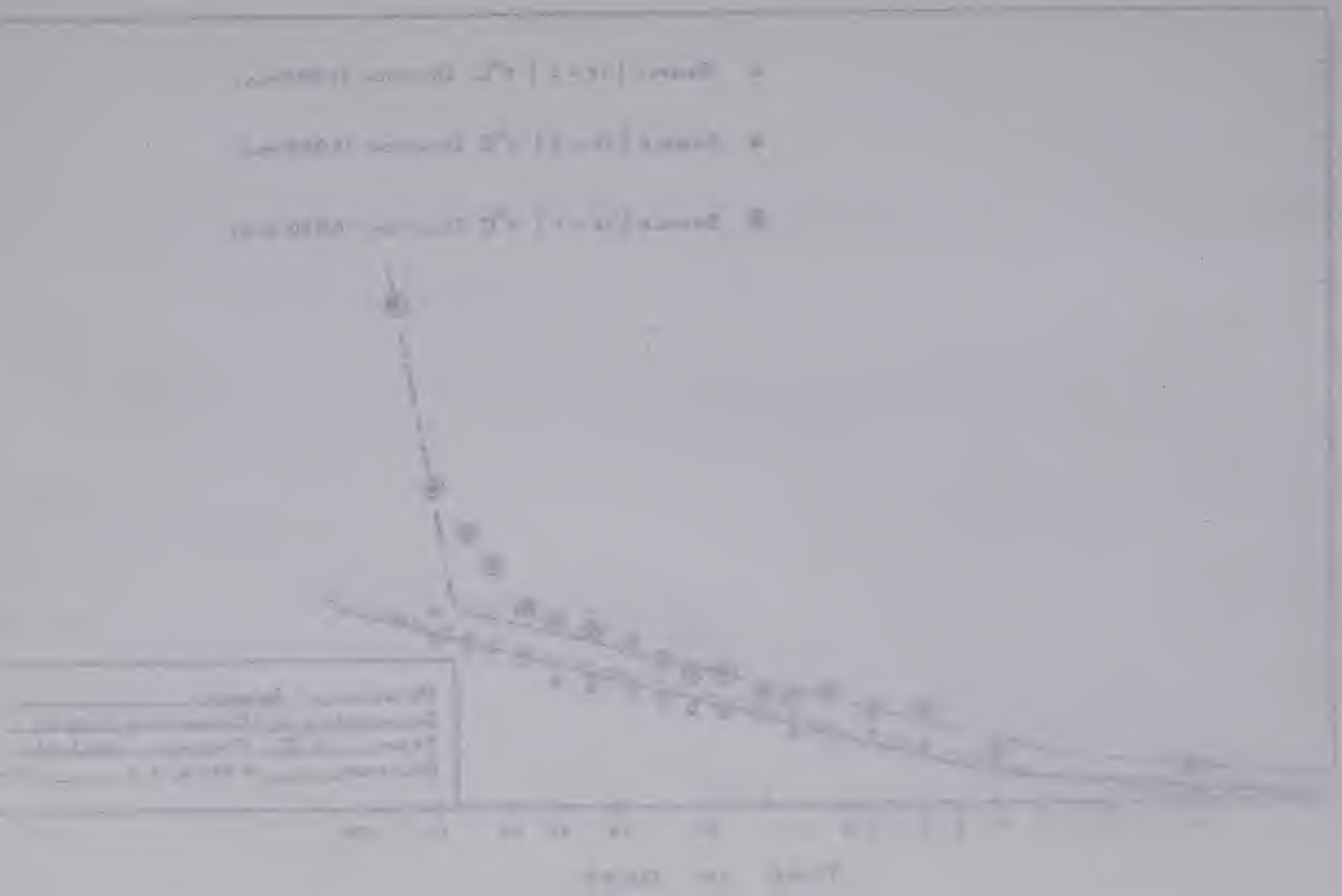


FIGURE: 4 - 38

B. O. D. CURVE "SEMI-LOG"



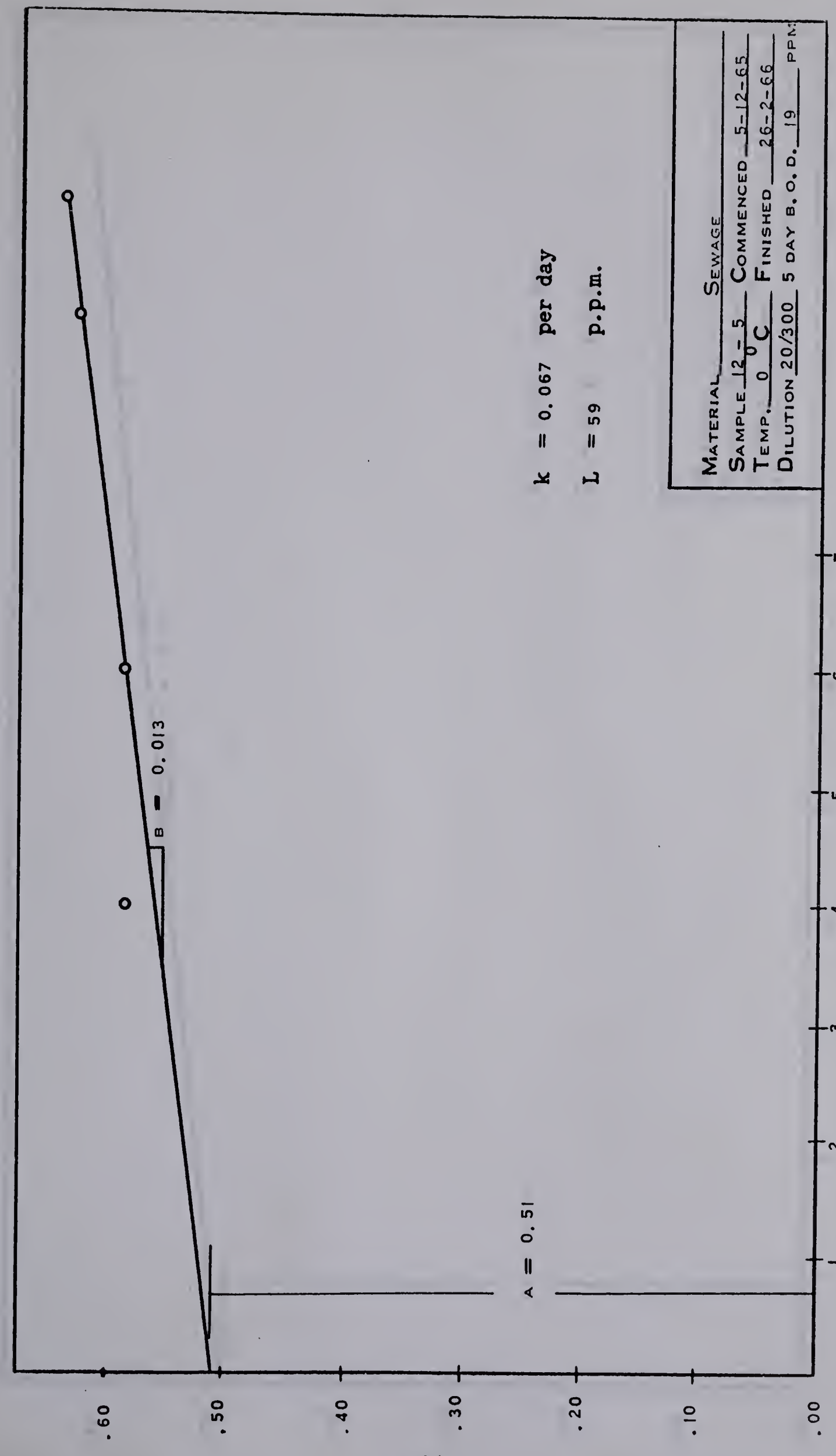


FIGURE: 4 - 39 B.O.D. CURVE CONSTANTS



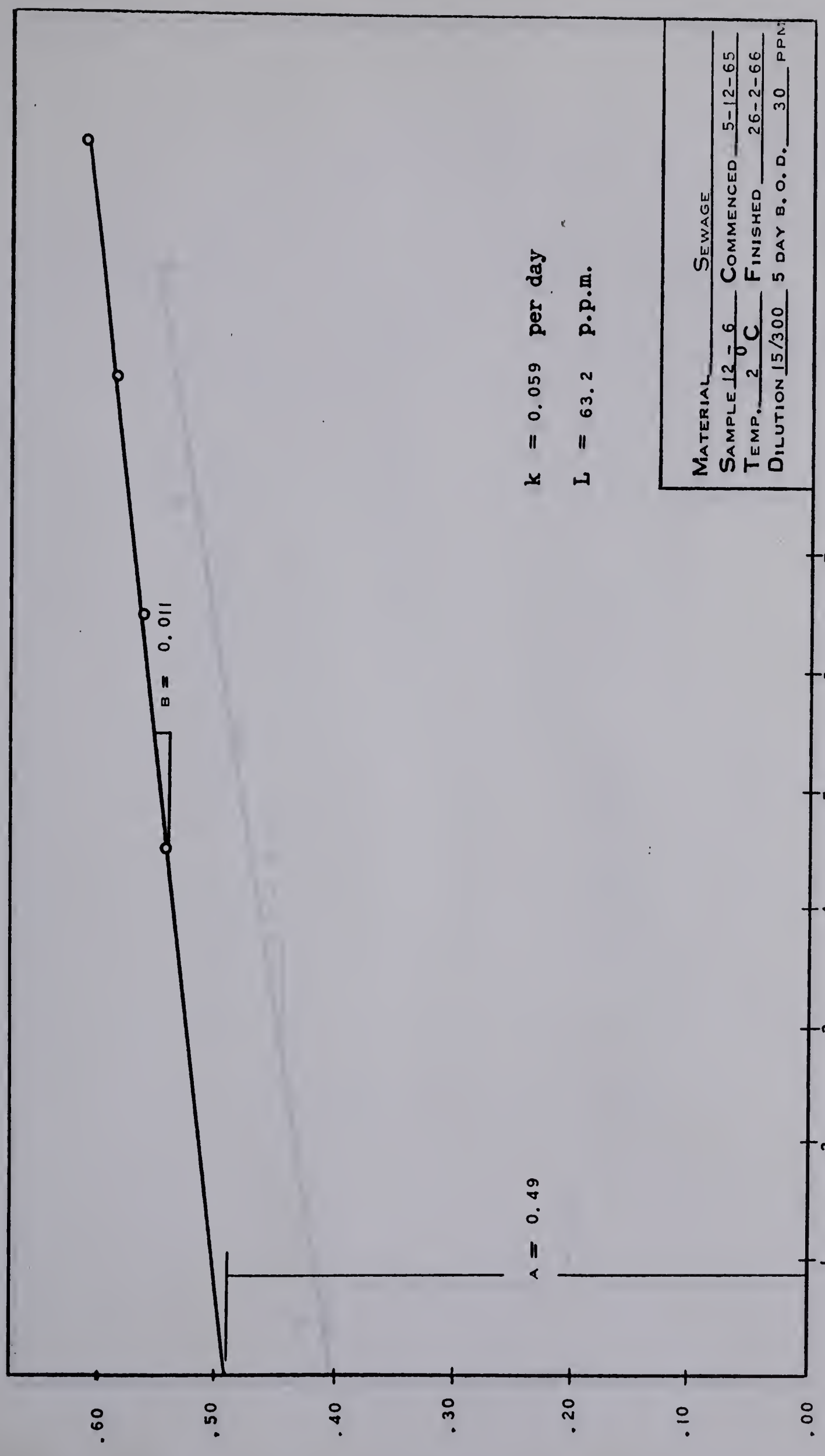
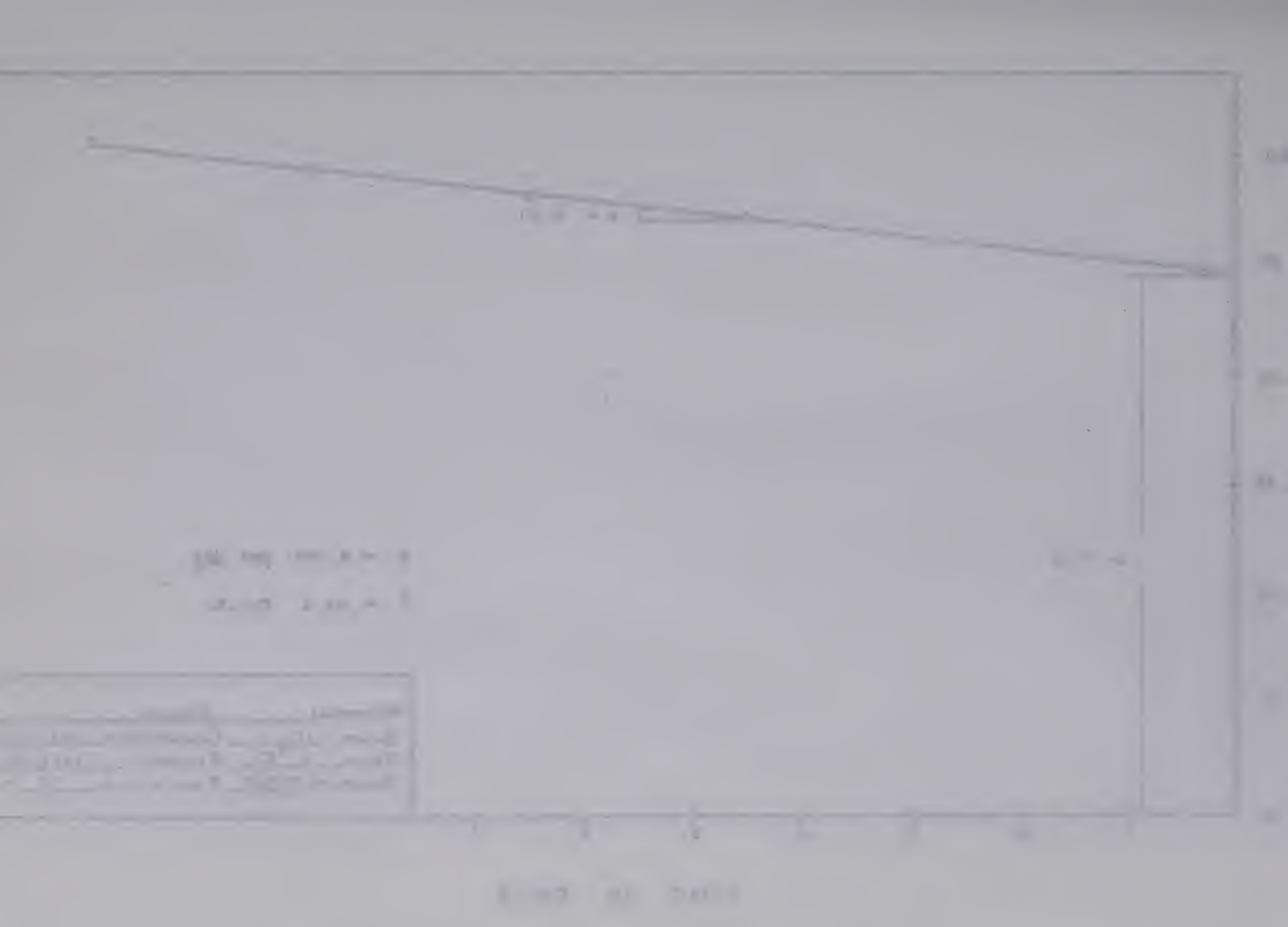


FIGURE: 4 - 40 B.O.D. CURVE CONSTANTS



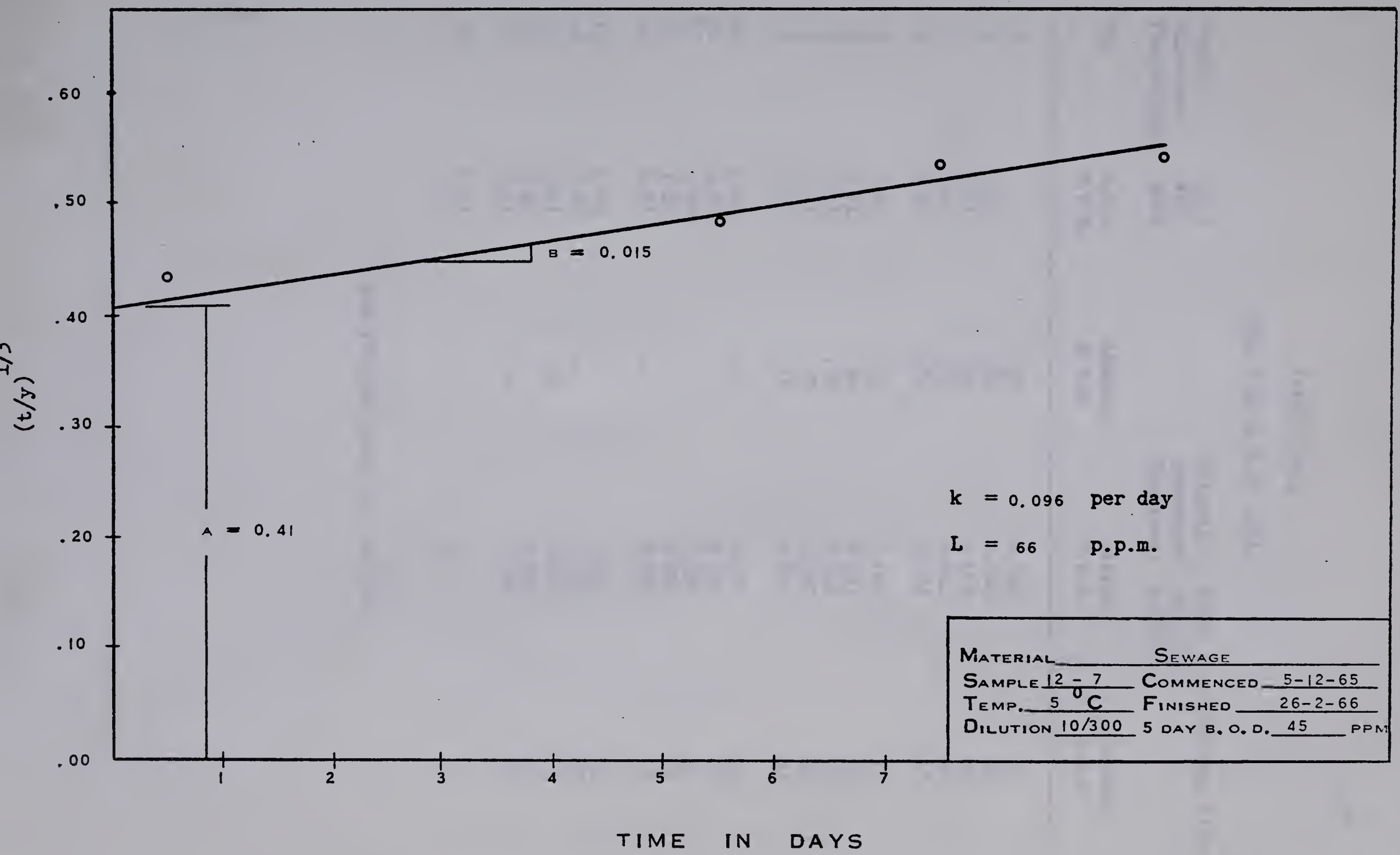


FIGURE: 4 - 41 B.O.D. CURVE CONSTANTS

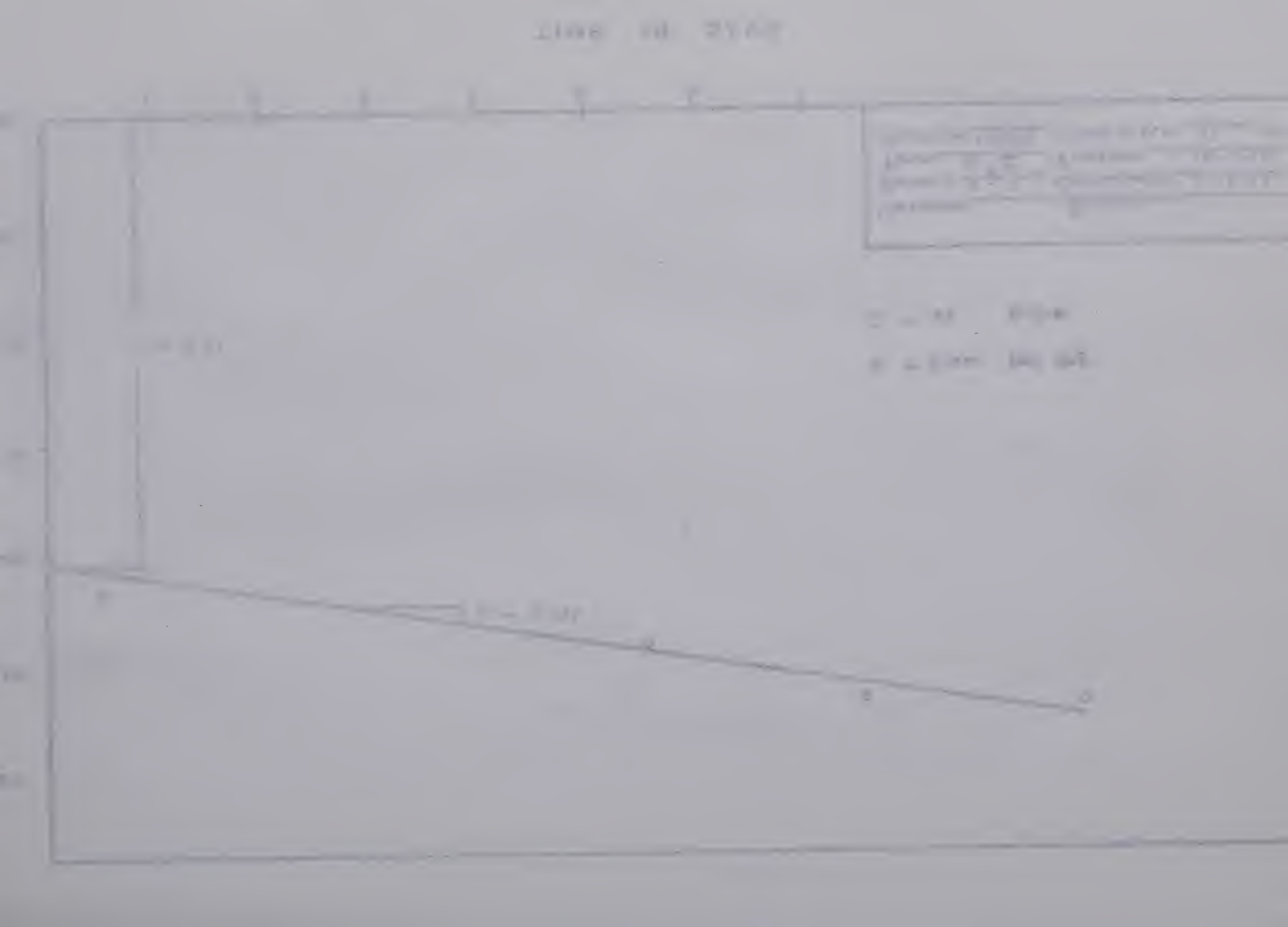


TABLE IV-24

LONG TERM B.O.D. DATA

Sample: 13-1
Dilution: Nil
Temperature: 20°C

Material: North Saskatchewan River
Commenced: 18/12/65
Finished: 12/1/66

Day	B.O.D. p.p.m.	Ammonia p.p.m.	Nitrite p.p.m.	Nitrate p.p.m.
0	-	.80	0.010	.45
1	0.43	.64	0.010	.34
2	1.11	.64	0.009	.33
3	1.26	.76	0.011	.28
4	1.63	.72	0.021	.45
5	2.01	.72	0.020	.71
6	1.71	.64	0.035	.44
7	1.91	.70	0.144	.09
8	2.91	.57	0.360	.00
9	3.41	.36	0.300	.11
10	4.26	.00	0.350	.36
11	4.51	-	0.260	.52
12	4.56	-	0.132	.14
13	5.16	-	0.002	.73
14	4.91	-	0.002	.69
15	4.88	-	0.003	.75
16	5.26	-	0.002	.77
17	5.41	.00	0.002	.71
18	5.46	-	0.002	.73
21	5.61	.00	0.002	.71
25	6.31	-	-	-

See FIGURES 4-42, 43, 44, 60

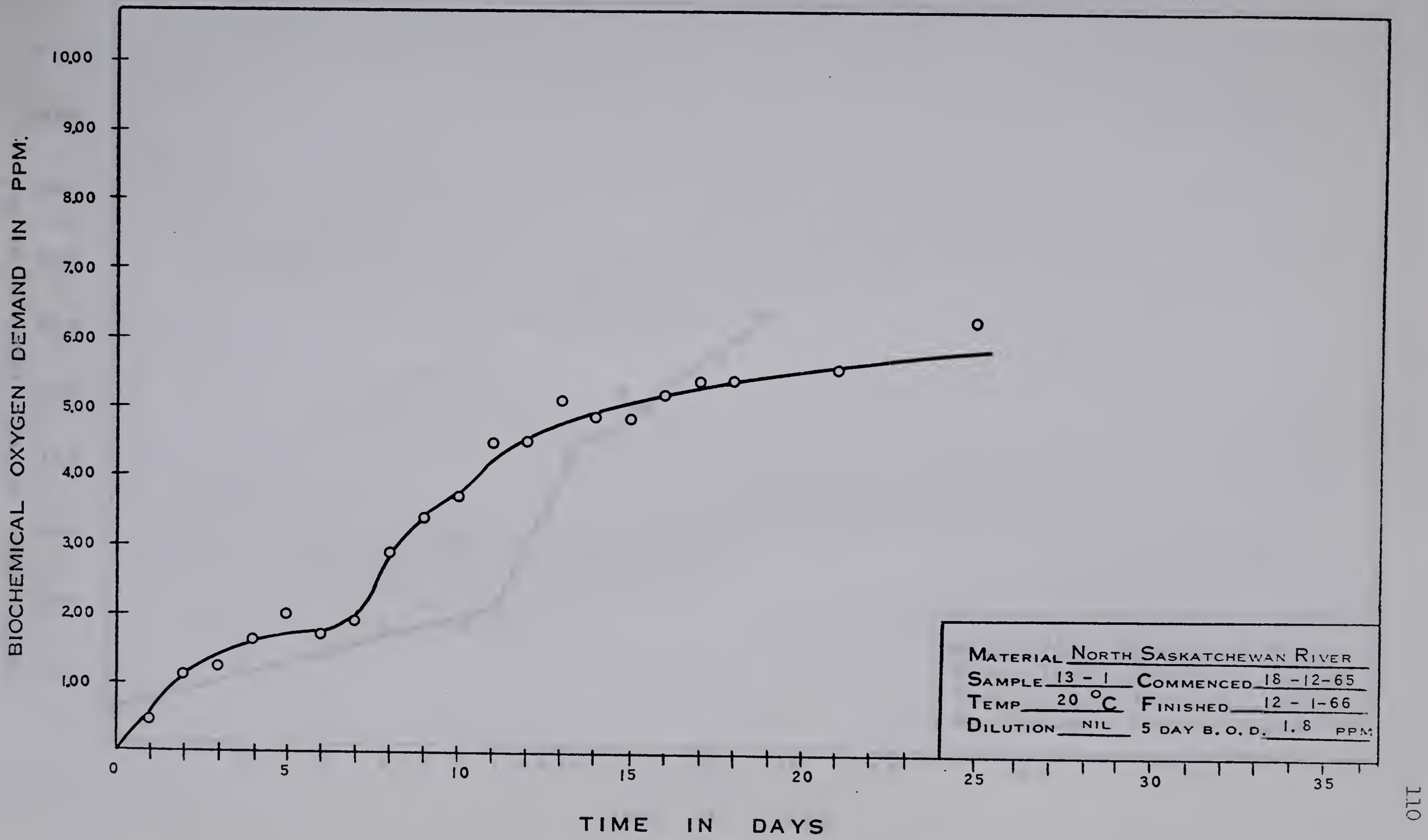
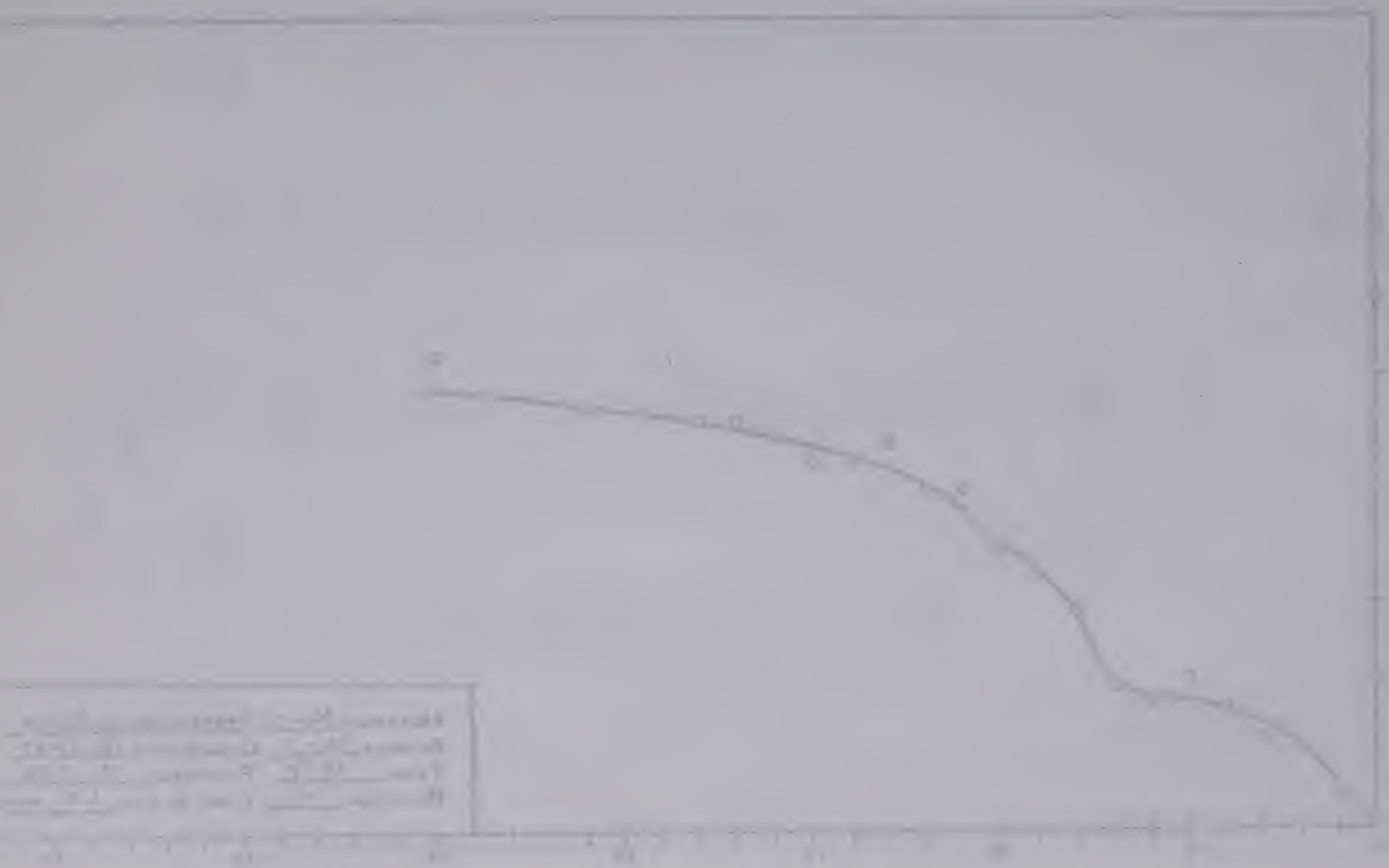


FIGURE: 4 - 42 NORMAL B.O.D. CURVE " ARITHMETIC PLOT"



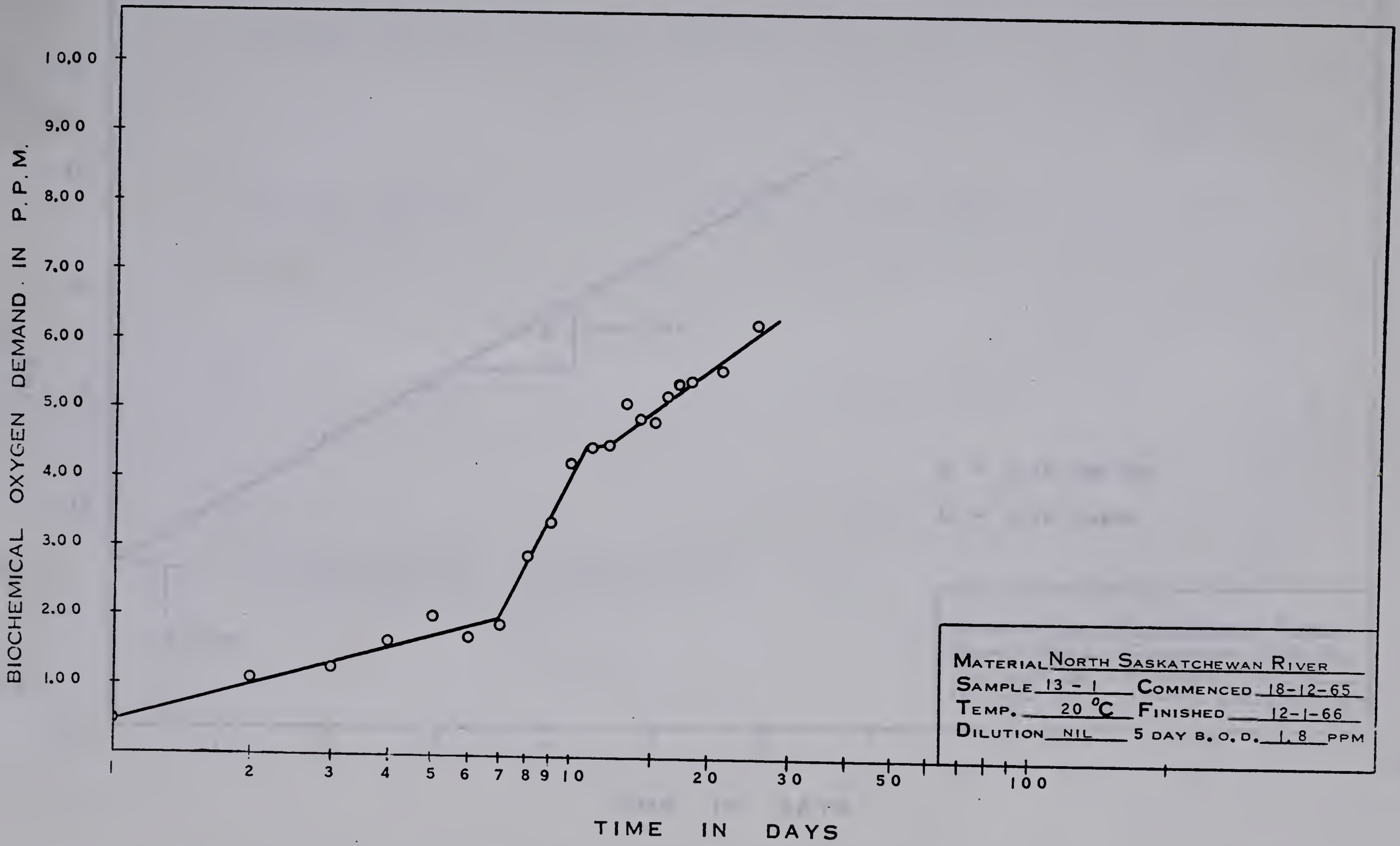
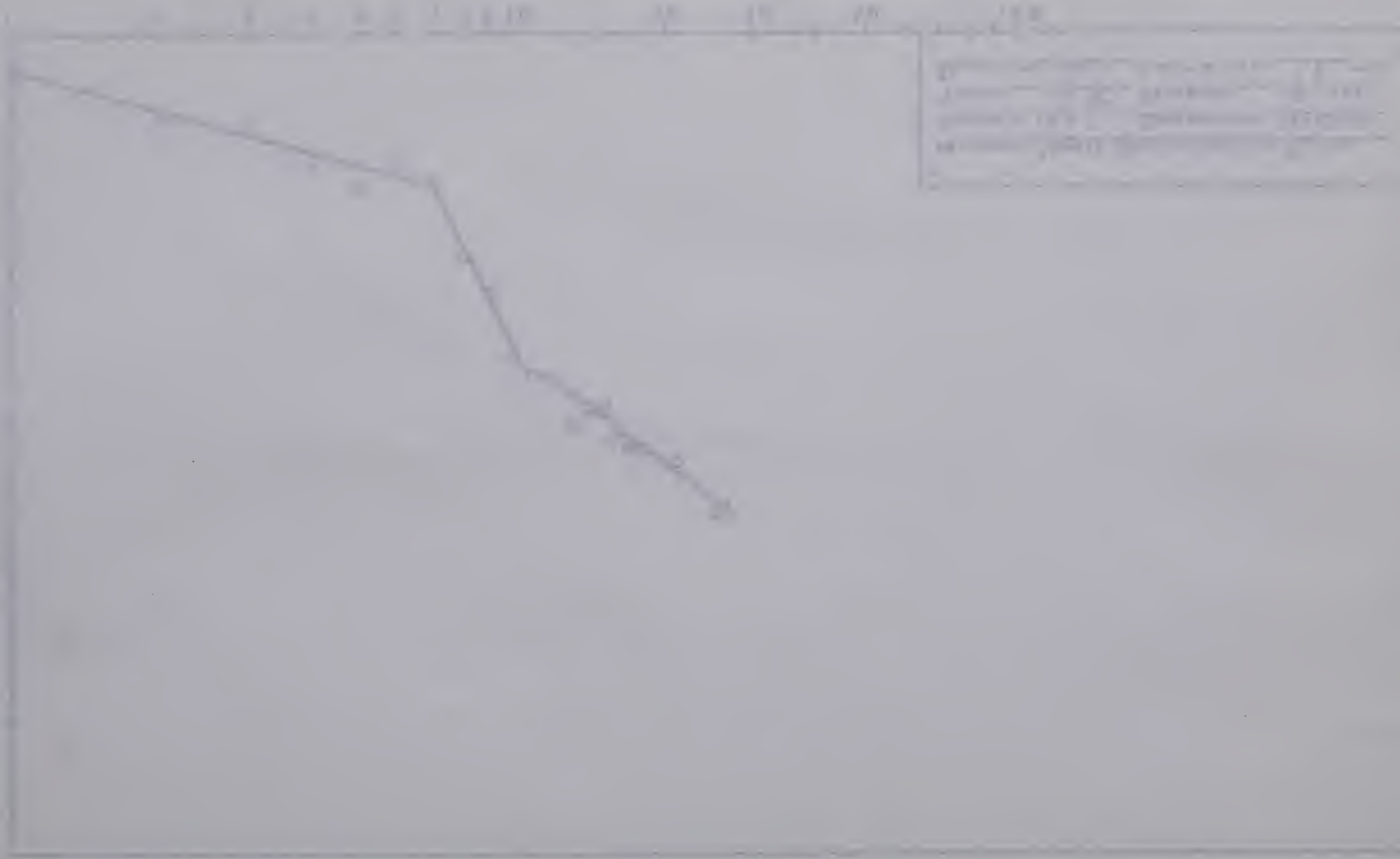


FIGURE: 4 - 43

B. O. D. CURVE "SEMI - LOG"



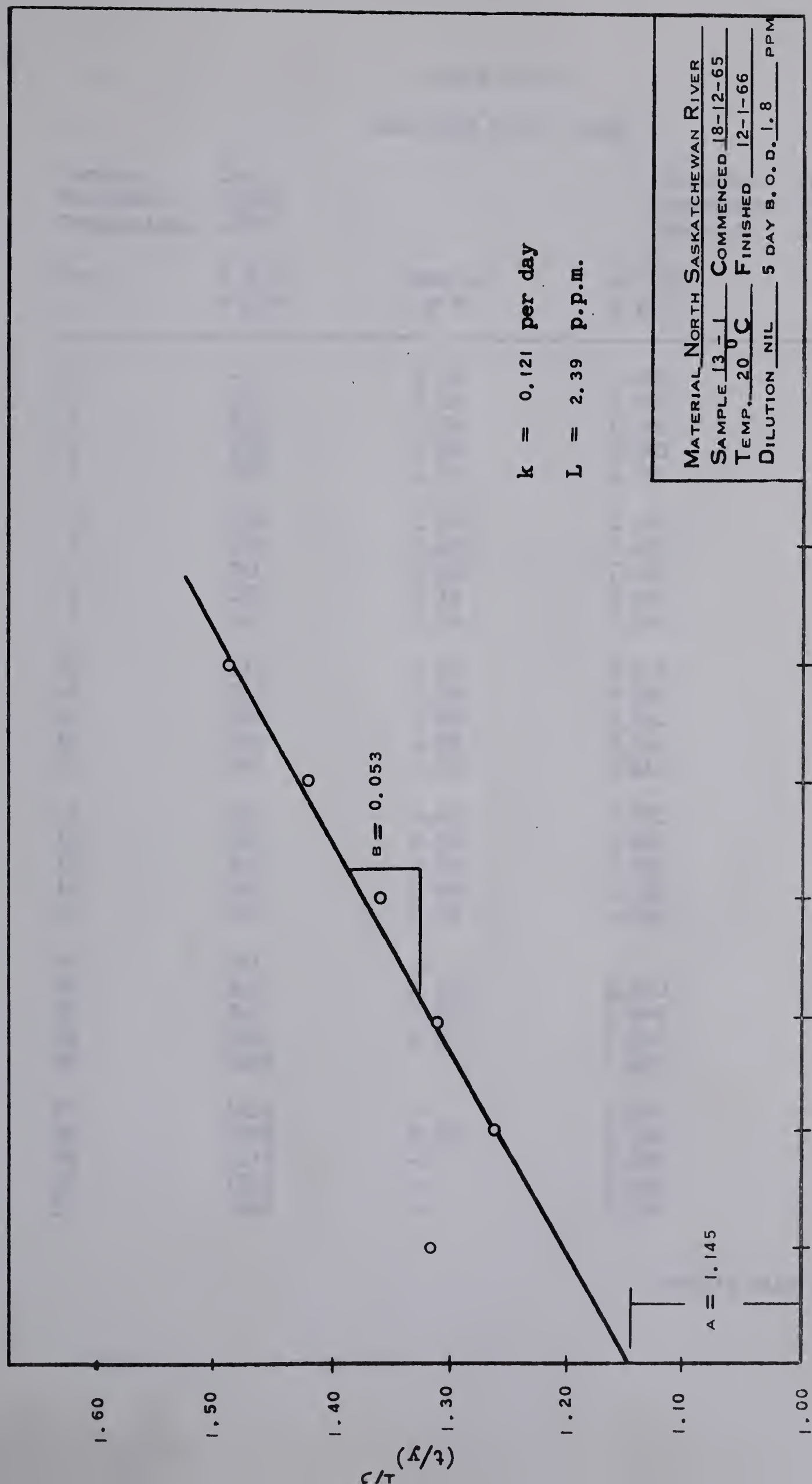


FIGURE: 4 - 44 B.O.D. CURVE CONSTANTS

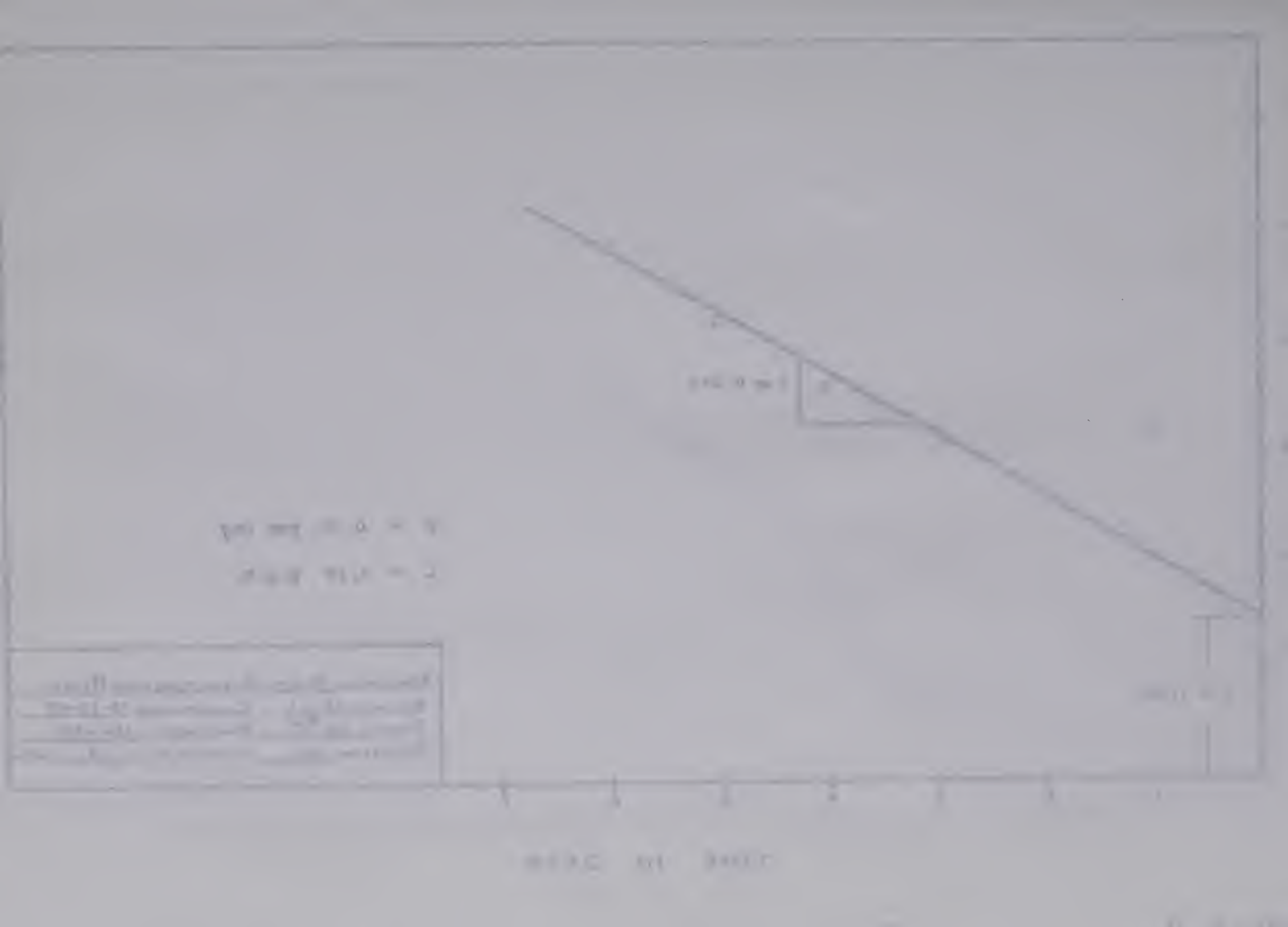


TABLE IV-25

LONG TERM B.O.D. DATA

Sample: 14-1 Material: Sewage
Dilution: 2/300 Commenced: 16/1/66
Temperature: 20°C Finished: 28/2/66

Day	B.O.D. p.p.m.	Ammonia p.p.m.	Nitrite p.p.m.	Nitrate p.p.m.
0	-	1.26	0.001	.06
1	60	1.24	0.002	-
2	150	1.28	0.002	-
3	188	1.26	0.001	.25
4	233	1.22	0.003	.00
5	255	1.22	0.002	.32
6	210	0.80	0.002	.19
7	240	1.32	0.003	.06
8	255	1.15	0.002	.16
9	315	1.36	0.004	-
10	315	1.15	0.013	.03
11	263	1.22	0.029	.40
12	368	1.28	0.054	.00
13	322	1.22	0.114	.00
14	390	1.00	0.140	.00
15	630	0.60	0.770	.00
16	865	0.50	0.840	.00
17	893	0.22	0.960	.00
18	960	0.06	1.100	.00
19	876	0.00	1.180	.00
20	881	-	-	-
22	840	0.00	1.160	.00
23	840	0.00	1.280	-
25	840	0.00	1.140	.00
26	1058	-	1.280	-
27	1010	-	1.220	.00
28	1005	0.00	1.180	.00
29	1135	-	1.080	-
30	1125	-	0.880	-
31	1065	-	0.360	.00

.....cont'd page 114

TABLE IV-25 continued from page 113

Day	B.O.D. p.p.m.	Ammonia p.p.m.	Nitrite p.p.m.	Nitrate p.p.m.
32	1100	-	0.003	.27
33	1135	-	0.002	.57
34	1125	-	0.000	.40
35	1085	-	0.000	.71
37	1305	-	-	.32
39	1306	-	-	.80
41	1260	-	-	.44
42	1270	-	-	.53
43	1304	-	-	.64

See FIGURES 4-45, 46, 47, 57

TABLE IV-26

LONG TERM B.O.D. DATA

Sample: 14-2
Dilution: 2/300
Temperature: 20°C

Material: Sewage, Cylinder A
Commenced: 16/1/66
Finished: 28/2/66

Day	B.O.D. p.p.m.	Ammonia p.p.m.	Nitrite p.p.m.	Nitrate p.p.m.
0	-	1.26	0.001	.06
1	75	1.24	0.002	-
2	188	1.28	0.002	-
3	245	1.26	0.002	.19
4	304	1.20	0.003	.05
5	394	1.18	0.002	.41
7	495	1.28	0.002	.10
8	-	-	0.002	-
9	576	1.18	0.001	-
11	624	1.12	0.002	.34
12	705	1.22	0.003	.23
13	-	-	0.004	-
14	770	0.62	0.009	-
15	-	1.22	0.014	-
16	876	1.12	0.030	.00
17	-	0.95	0.054	-
18	1000	1.12	0.106	.06
19	1047	1.06	0.200	.00
20	1150	0.80	0.390	.00
21	1290	0.56	0.580	-
22	1462	0.30	0.860	.00
23	1572	-	1.040	-
25	1690	0.00	1.100	.00
26	1725	-	1.040	-
27	1715	-	1.020	.00
28	1750	0.00	1.000	.00
29	1820	-	0.960	-
30	1850	-	1.020	-
31	1905	-	0.960	.00
32	1930	-	0.940	.00

..... cont'd page 116

TABLE IV-26 continued from page 115

Day	B.O.D. p.p.m.	Ammonia p.p.m.	Nitrite p.p.m.	Nitrate p.p.m.
33	1994	-	0.970	.00
34	2030	-	0.860	.00
35	2100	-	0.860	.00
36	2195	-	0.870	.00
37	2240	-	0.760	.00
38	2320	-	0.660	.00
39	2395	-	0.540	.32
40	-	-	0.290	-
41	2470	-	0.115	.29
42	2585	-	0.001	.37
43	2650	-	0.000	.51

See FIGURES 4-45, 46, 48, 57

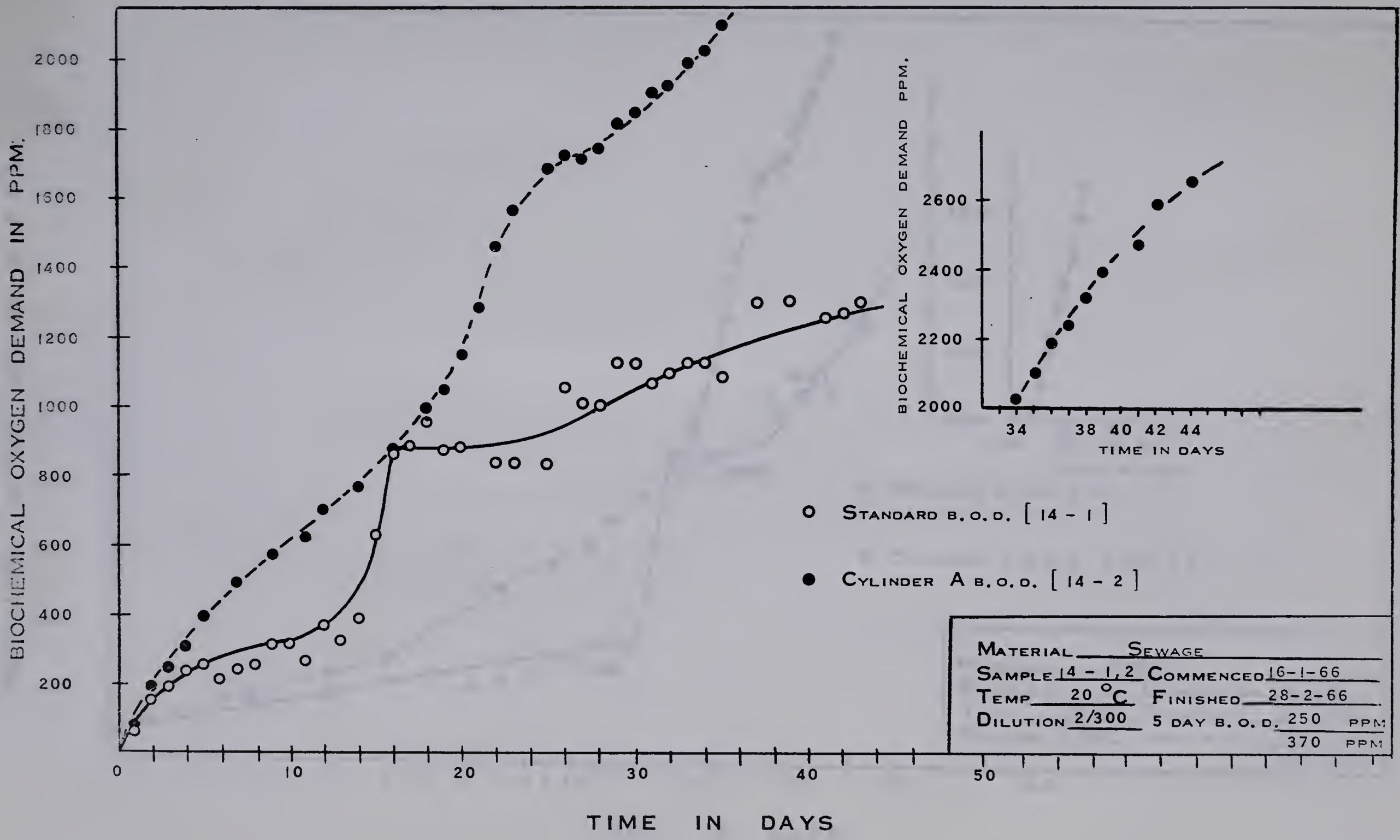


FIGURE: 4 - 45 NORMAL B.O.D. CURVE " ARITHMETIC PLOT"



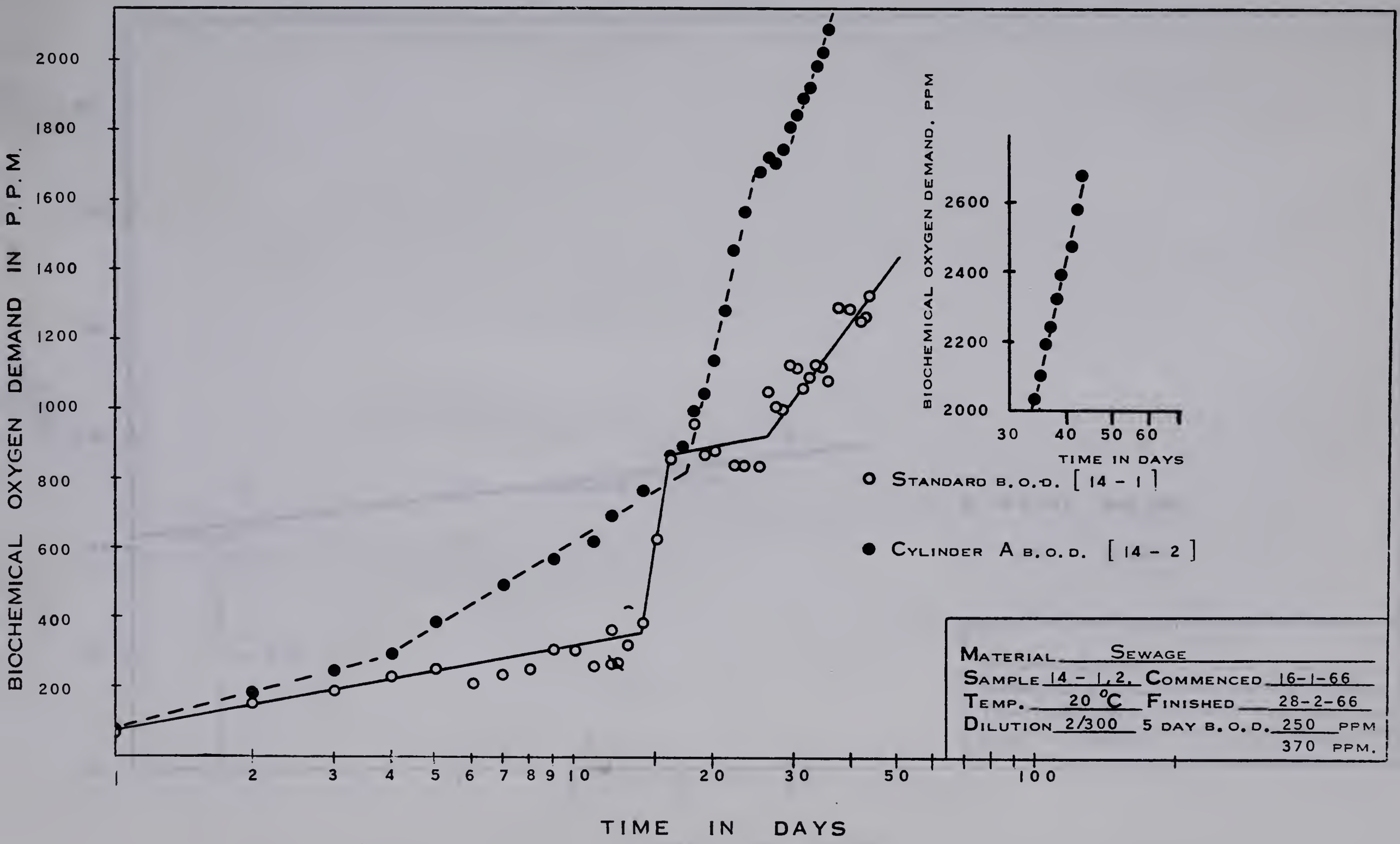
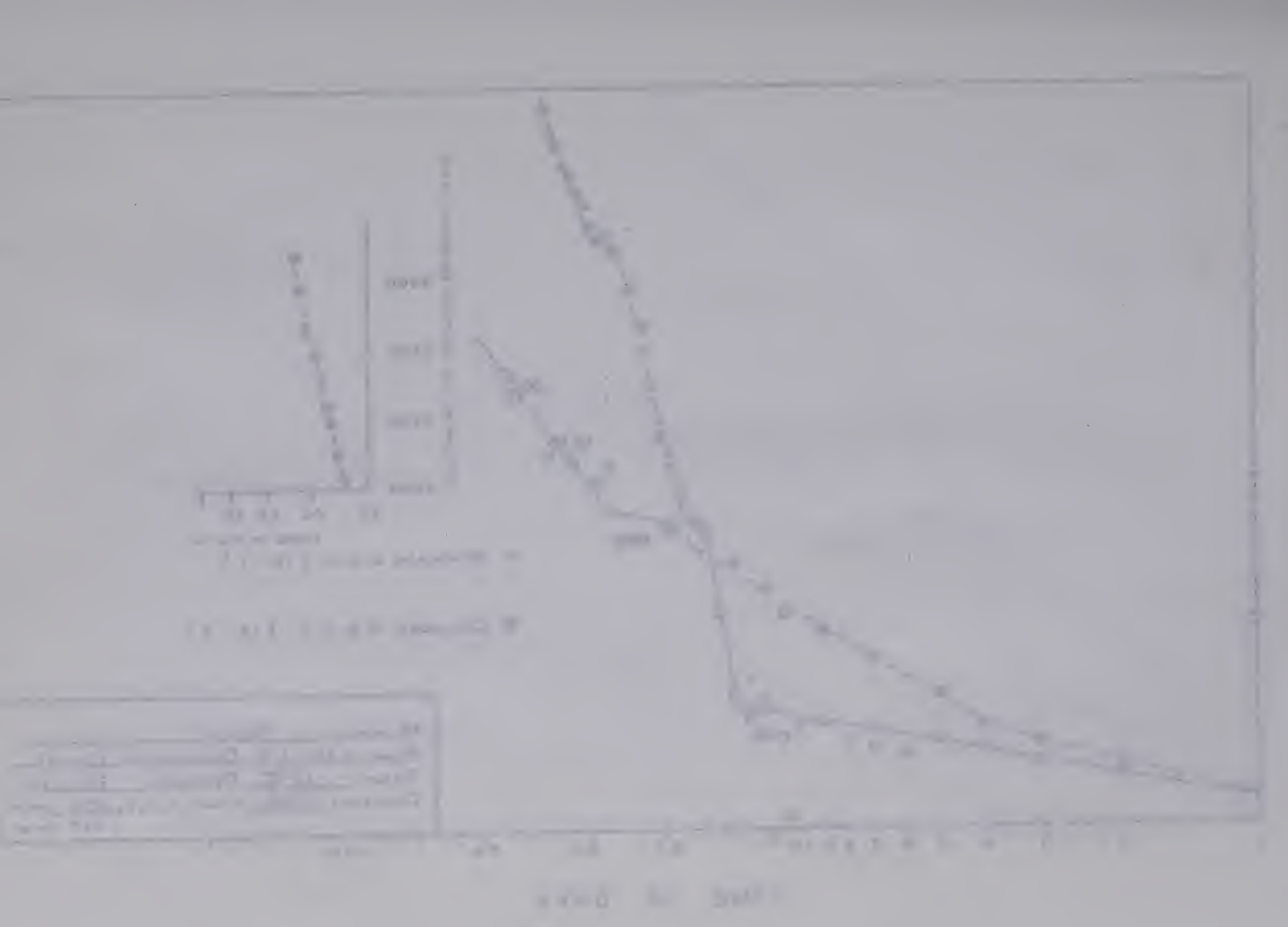


FIGURE: 4 - 46 B. O. D. CURVE "SEMI - LOG"



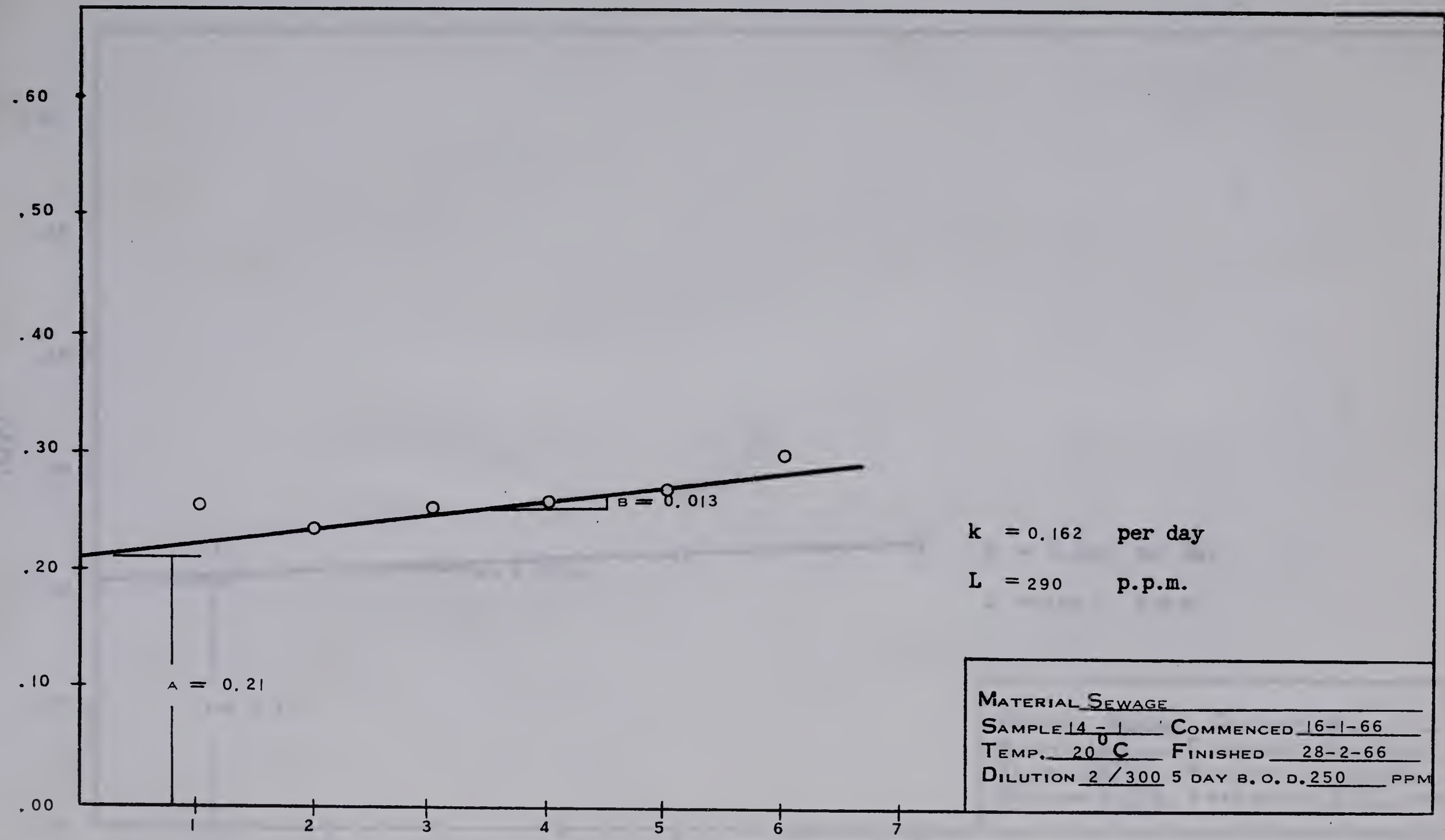


FIGURE: 4 - 47 B.O.D. CURVE CONSTANTS



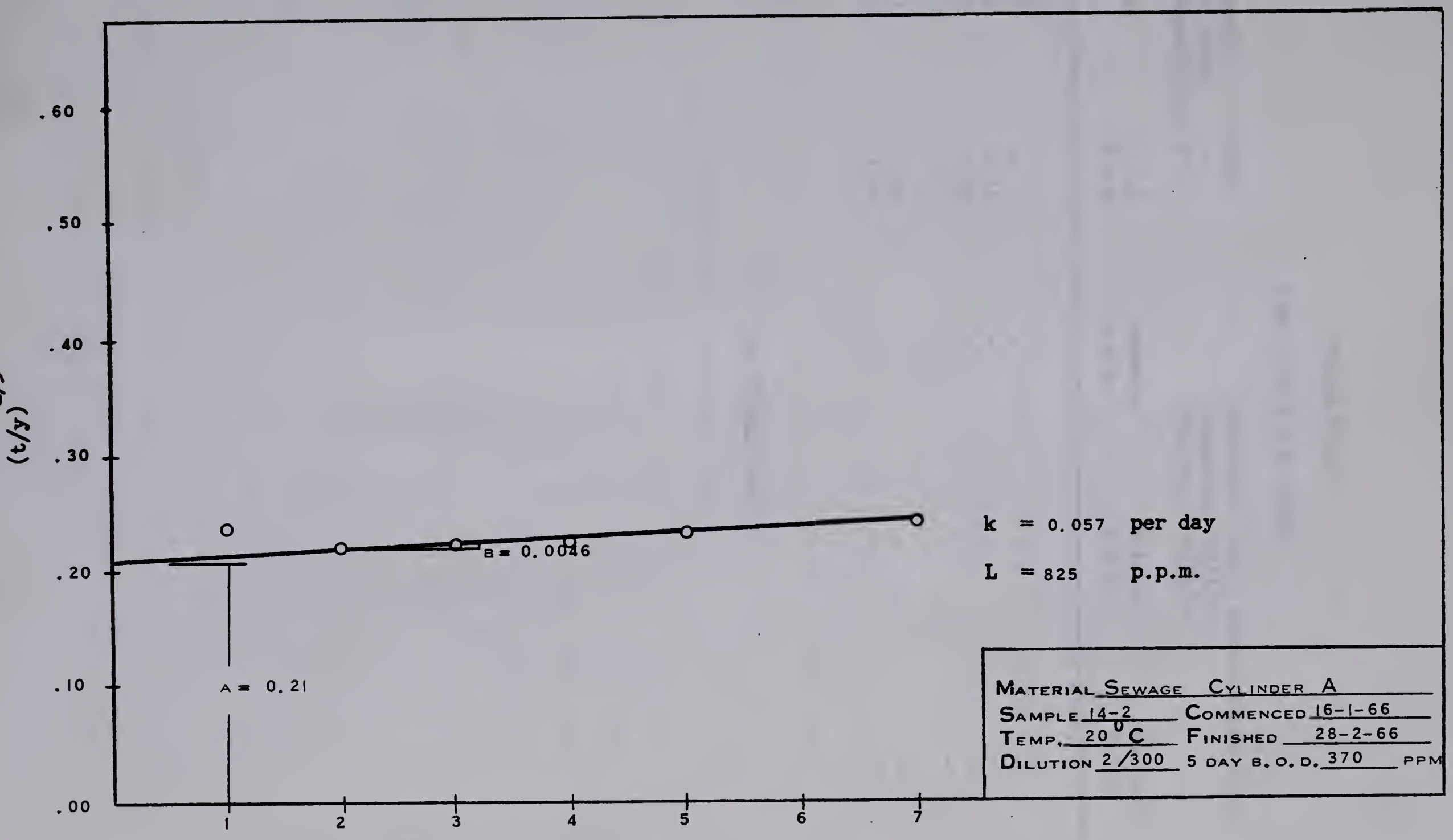


FIGURE: 4 - 48

B.O.D. CURVE CONSTANTS

TABLE IV-27

LONG TERM B.O.D. DATA

Sample: 19-1 Material: North Saskatchewan River
Dilution: - Commenced: 18/3/66
Temperature: 0°C Finished: 24/3/66

Day	B.O.D. p.p.m.	Ammonia p.p.m.	Nitrite p.p.m.	Nitrate p.p.m.
0	-	-	-	-
1	0	-	-	-
2	0.40	-	-	-
3	0.70	-	-	-
4	0.75	-	-	-
5	0.87	-	-	-
6	1.20	-	-	-

See FIGURE 1-2

Text continued from page 47

TABLE IV-6 shows the discrepancy of the calculated value of "L" and the value of "L" obtained from the plotted B.O.D. data. It is felt that the value of "L" estimated from the plotted data is the more reliable.

In the 0°C to 5°C range the deoxygenation rate constants "k" were shown, as in FIGURE 4-4, to increase from 0.043 to 0.096 per day with an increase in temperature. Biological activity decreases as the temperature decreases, therefore the rate or velocity of deoxygenation would be correspondingly lower as shown.

The ultimate first stage B.O.D. "L" by definition is the amount of oxygen required for the biological oxidation of carbonaceous matter, which for any one series of tests should be the same. At lower temperatures some of the carbonaceous compounds are not as readily broken down which would result in lower values of "L" at lower temperatures. FIGURES 4-30, 37 show this to be true with the 0°C values of "L" being approximately one third of that obtained at 20°C. The range of calculated values of "L" is too great to permit further comment, other than that series twelve of the test, TABLE IV-3, was in agreement.

With the Thomas method for determining the B.O.D. curve constants "k" and "L", when lower values of "k" are obtained, the value of "L" is unduly influenced by "k" (Ludzack 1953). To overcome this undue influence of "k" upon "L" another method for determining the values of "k" and "L" should be employed, i.e. the method of moments.

In some tests, especially those conducted at lower temp-

eratures, a lower rate of dissolved oxygen depletion occurred for the first few days. This is a period of adjustment in which the bacteria adapt themselves to their new environment. This period of adjustment is known as the "lag time". The lag time was found to be longest in tests conducted at the lower temperatures (six days at 0°C) with no lag time occurring at 20°C. Acidizing the sewage sample also created a short lag time.

The lag period where it occurred was determined mainly from the semi-log plot. By extending the best fit line of the "log phase" of growth, for the carbonaceous stage, the lag time was taken at the intercept of the "time axis" (See FIGURE 4-21) and this value taken as zero time.

The B.O.D. at the lag time was obtained from the plot and subtracted from all the B.O.D. values in the test. The axes of the B.O.D. versus time plot were in effect shifted to the right by an amount equal to the lag time, and raised by an amount equal to the lag time B.O.D.

In order to overcome this initial lag period it may be possible to prevent it by seeding the sample. The seed used would have to be incubated at the temperature of the test for a period of six days to ensure that the bacteria had adjusted to the lower temperatures. This would necessitate the running of two sets of tests in place of one, and the B.O.D. created by the seed would have to be accounted for as per Standard Methods (1960).

FIGURE 4-13 did not conform to the preceeding method due to a seven day period wherein there was little change in the B.O.D. This has been referred to as an "initial biological acceleration" by Orford and Ingram (1953). The ammonia and nitrite tests show that nitrification did not occur within a 100 day period, therefore, the period after nine days was taken as the start of the carbonaceous curve. and the B.O.D. values adjusted by 110 p.p.m. No explanation for this period of no deoxygenation is offered.

IV-3 Temperature Effect

In order to determine "k" at another temperature once one value of "k" is known. Arrhenius' equation (Equation III-3) was evaluated as outlined in Section III. The best fit line from a plot of log "k" versus 1/T (in absolute degrees), for temperatures in the 0°C to 5°C. FIGURE 4-49, gave a slope of 5,880. From this slope the activation energy "E", was calculated to be 26,800 calories. Since "E" changes with temperature the value of "E" equal to 26,800 is only accurate in the 0°C to 5°C range. Substituting this value into Equation III-3, the 0° range constant was found to be, accurate to the nearest hundredth, 0.04 per day when using the 5°C "k" value of 0.096 per day. The observed value of "k" at 0°C was 0.043 per day for sewage samples.

Phelps states that "at lower temperatures "E" varies to as much as 20,000 calories at 0°C".

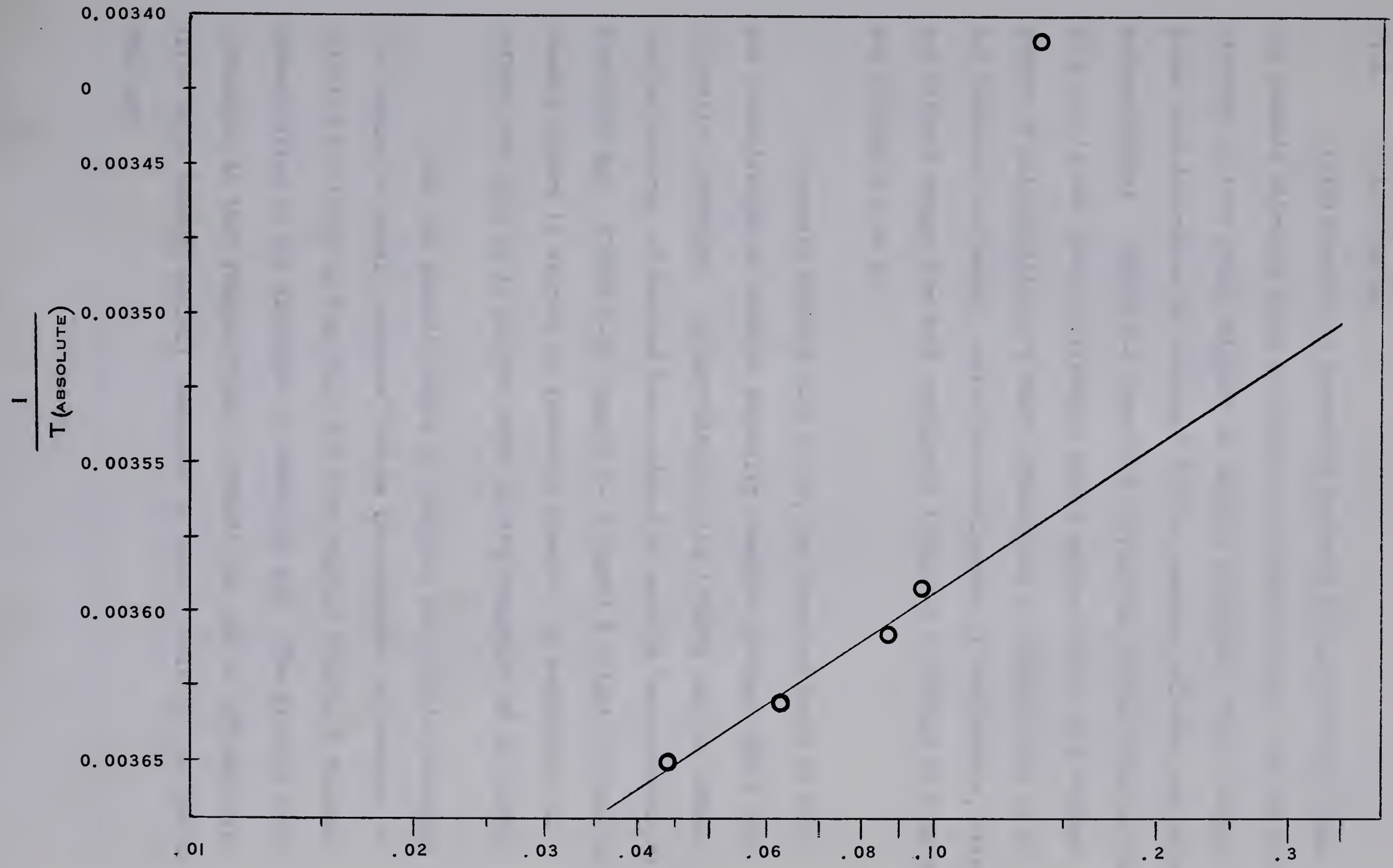
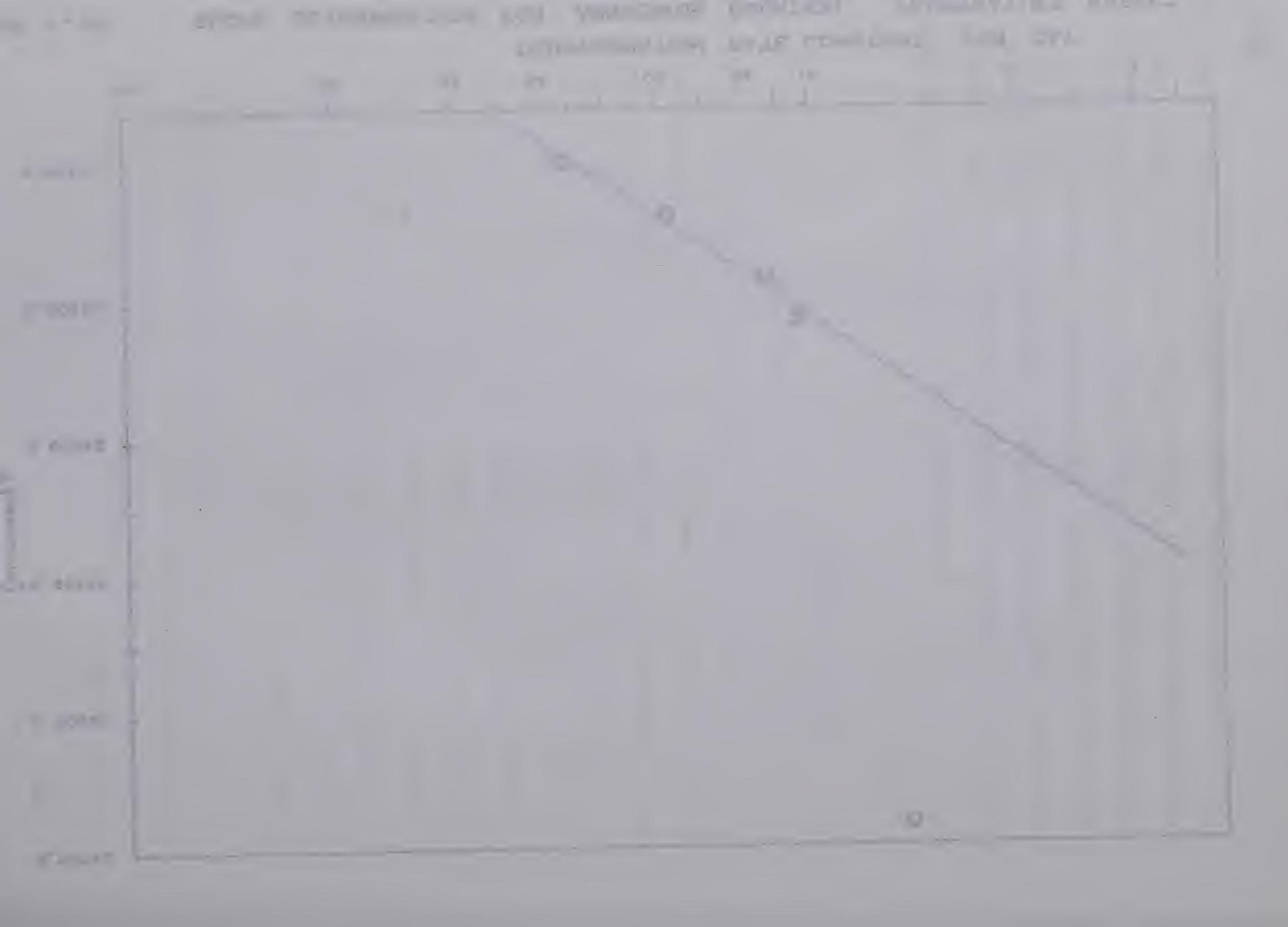


FIGURE 4 - 49 SLOPE DETERMINATION FOR ARRHENIUS EQUATION TEMPERATURE EFFECT



IV-4 Nitrification

Nitrification as described proceeds in two definite steps, the ammonia nitrogen being oxidized to nitrite nitrogen, and the nitrite nitrogen in turn being oxidized to nitrate nitrogen. These various steps were determined by running B.O.D.'s, ammonia, nitrite and nitrate determinations. FIGURE 2-2 shows the correlation of the semi-log plot of B.O.D.'s and the nitrification stages against time. The various phases of nitrification are shown graphically in FIGURES 4-50 to 57 and indicate the length, degree and overlapping of the ammonia, nitrite and nitrate stages for data previously tabulated in TABLES IV-8 to 26 and FIGURES 4-8 to 48.

Observing FIGURES 4-50 to 57, for standard tests at 20°C, the concentration of ammonia generally remained constant until nitrification commenced. On approximately the twelfth day the ammonia started to drop off and had been reduced to zero by the sixteenth to twentieth day. FIGURE 4-50 (sample 3-1) showed a slight increase of ammonia before it started to decrease; however, no explanation is offered for this as it did not occur in the remainder of the tests.

When the ammonia starts to decrease the nitrite concentation begins to slowly increase (due to the oxidation of ammonia to nitrite) for three to four days and then rapidly reaches a maximum concentration by the sixteenth to twentieth day. The nitrite concentration in turn remains fairly constant for ten to fifteen days, after which time it rapidly decreases to trace levels by the 32nd to 38th day.

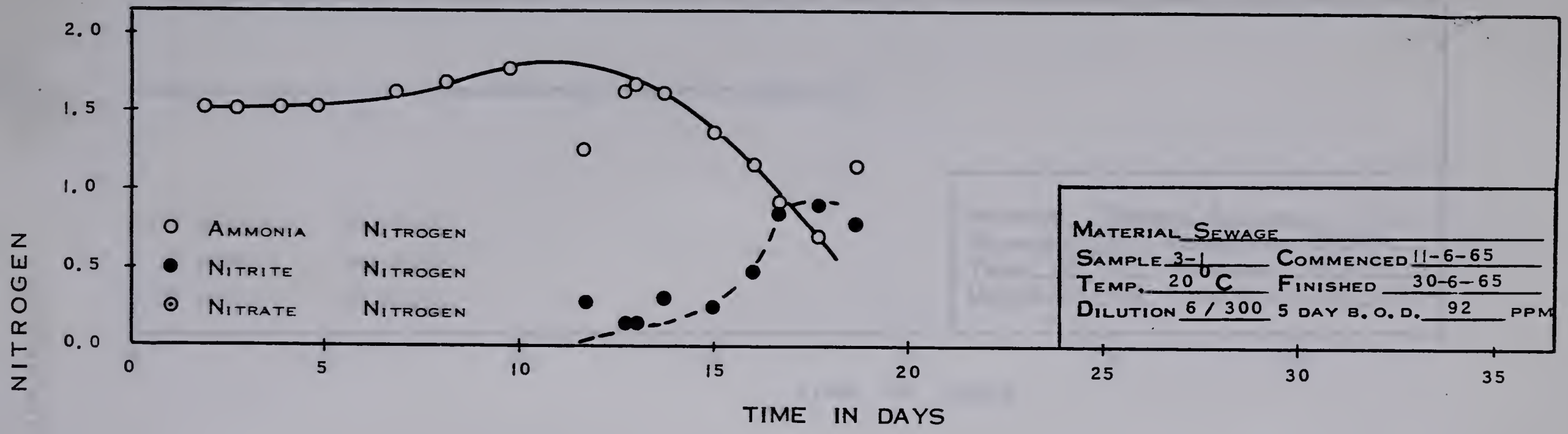
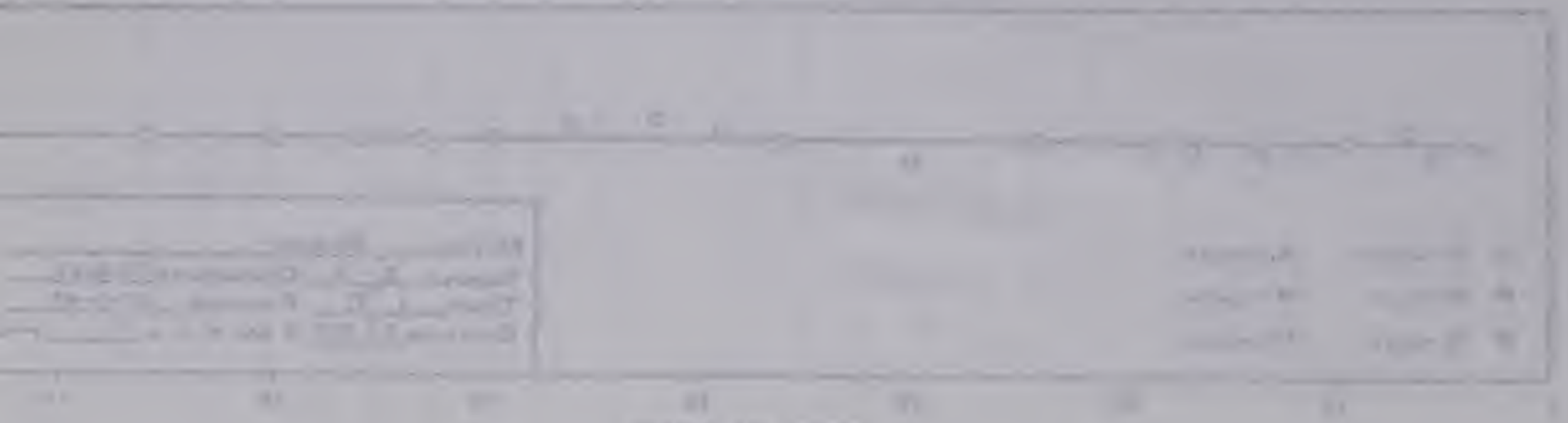
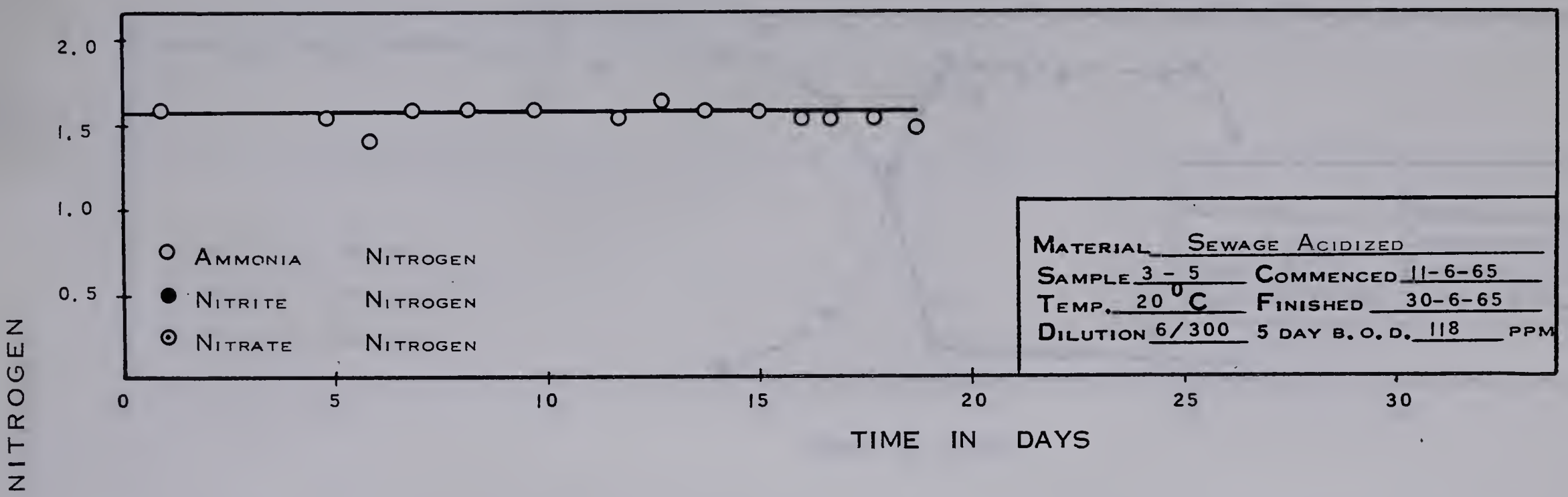


FIGURE: 4 - 50 NITRIFICATION STAGES







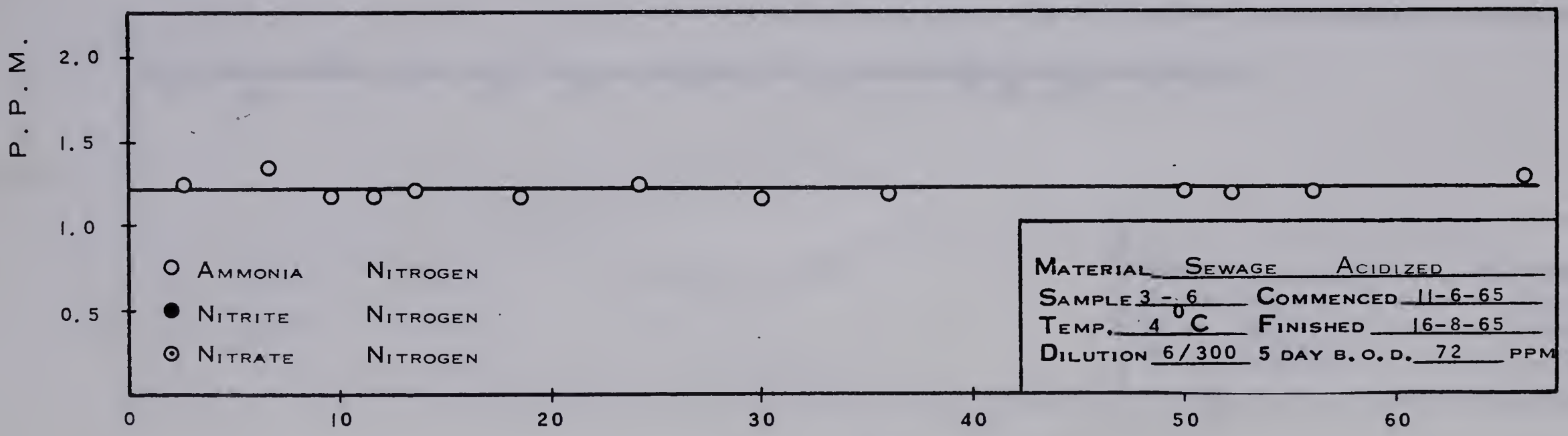


FIGURE: 4 – 51 NITRIFICATION STAGES





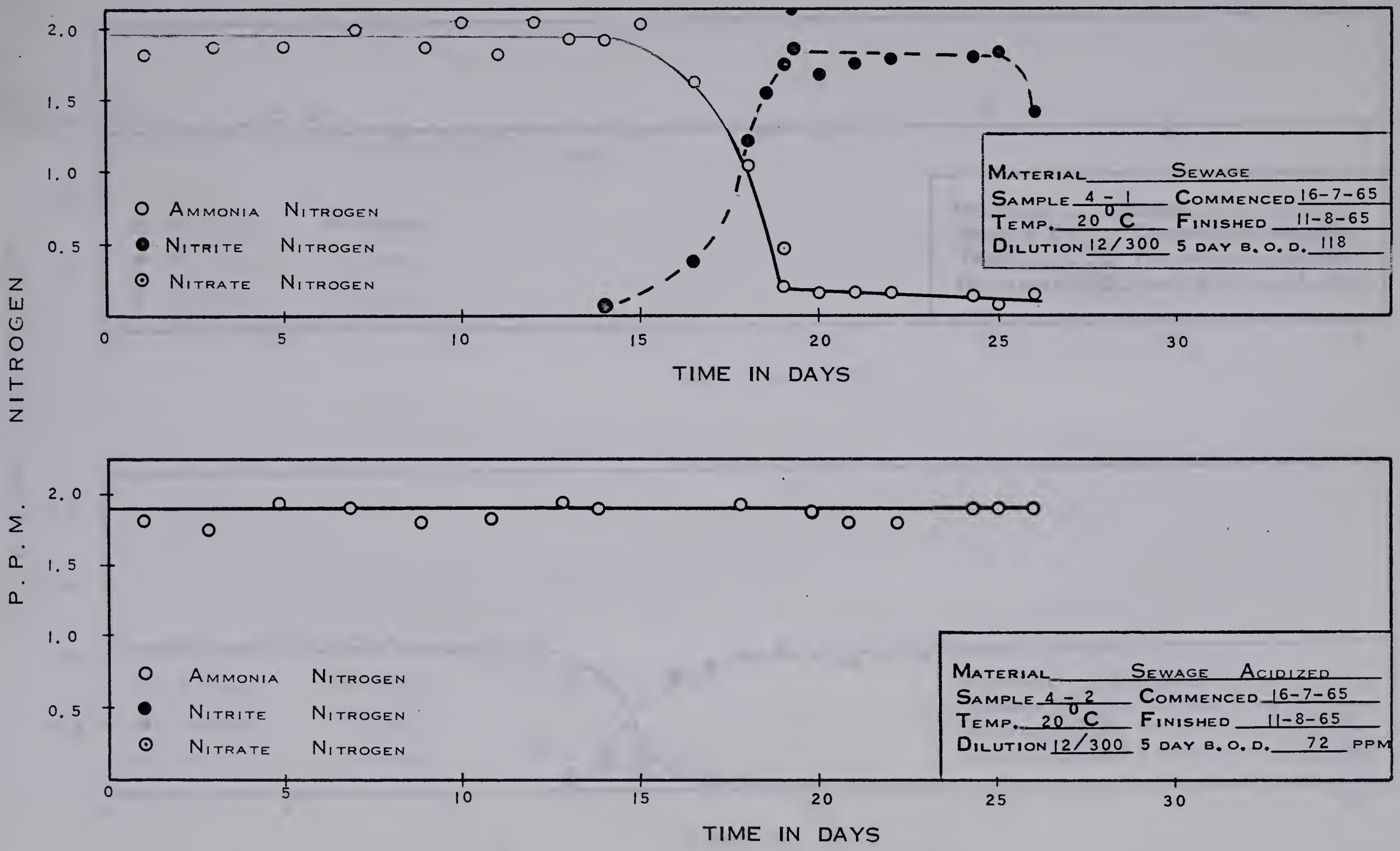
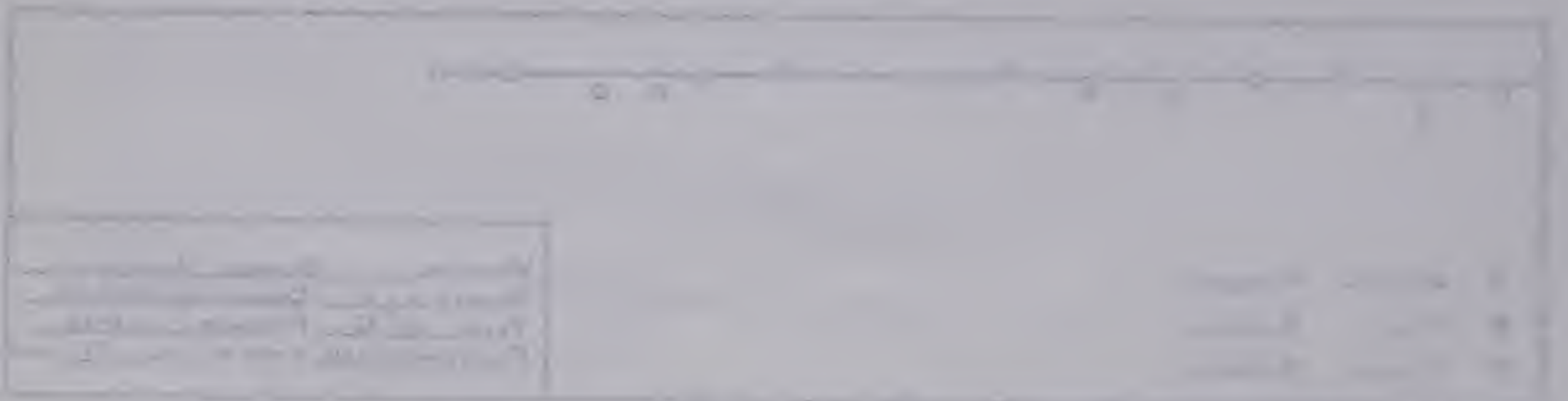
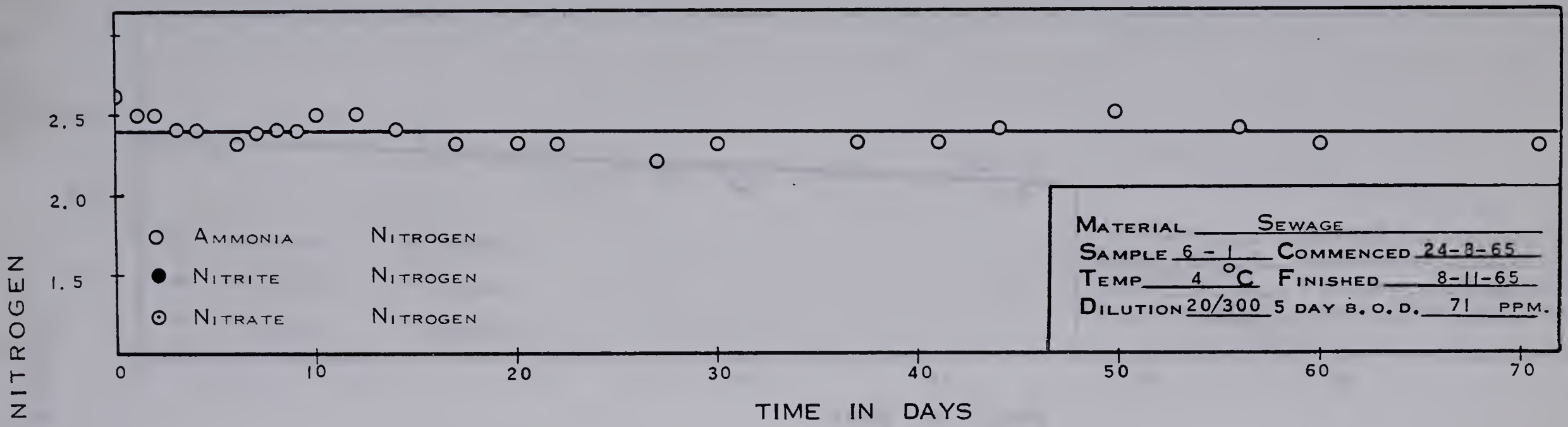


FIGURE: 4 - 52 NITRIFICATION STAGES







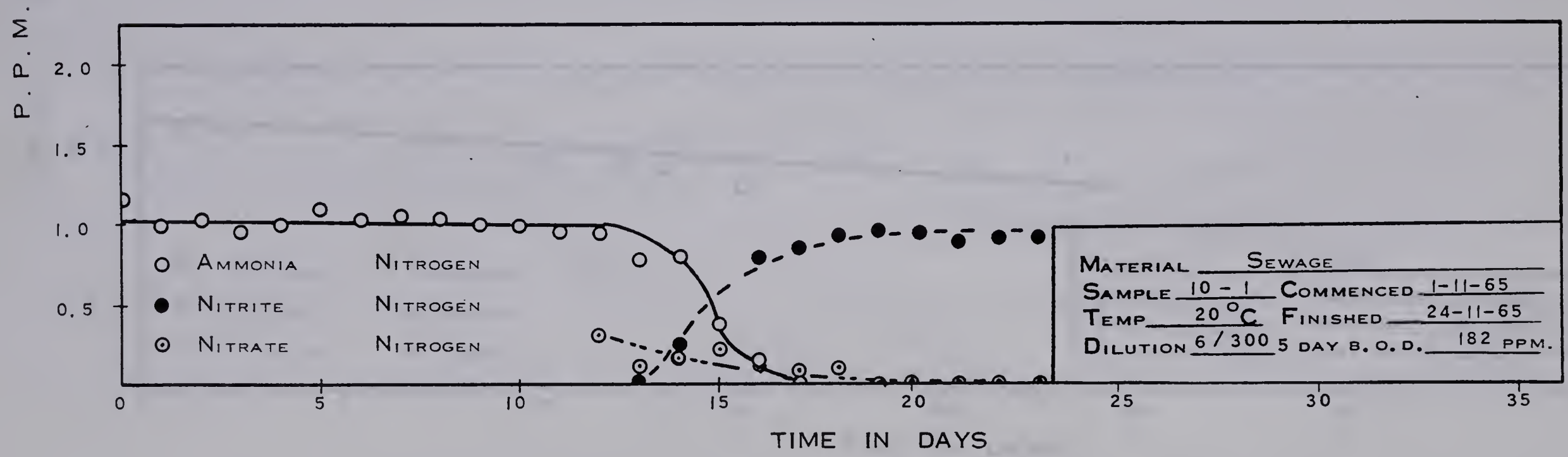
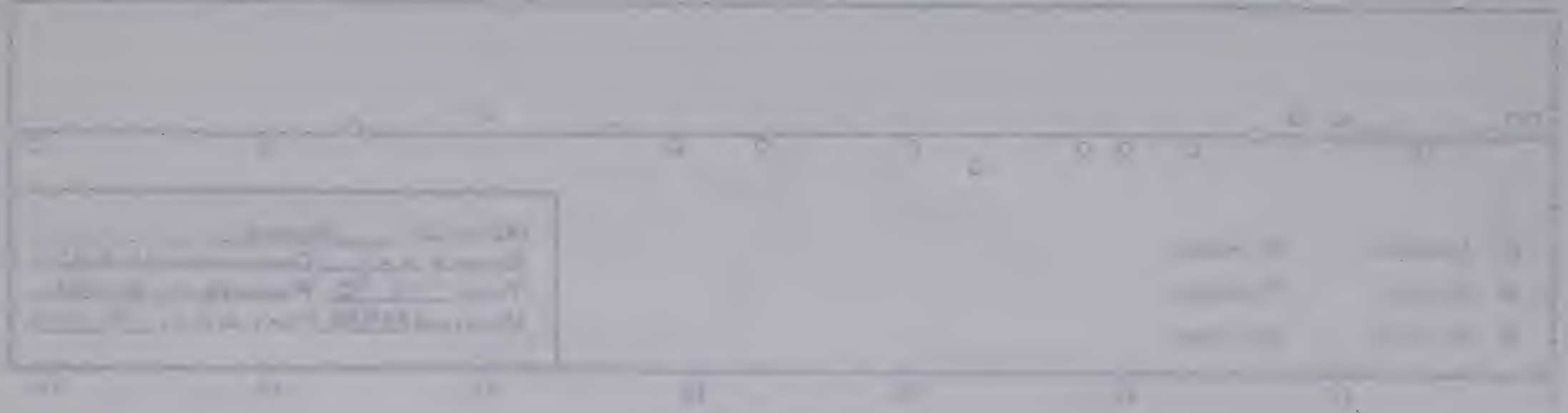


FIGURE: 4 - 53 NITRIFICATION STAGES





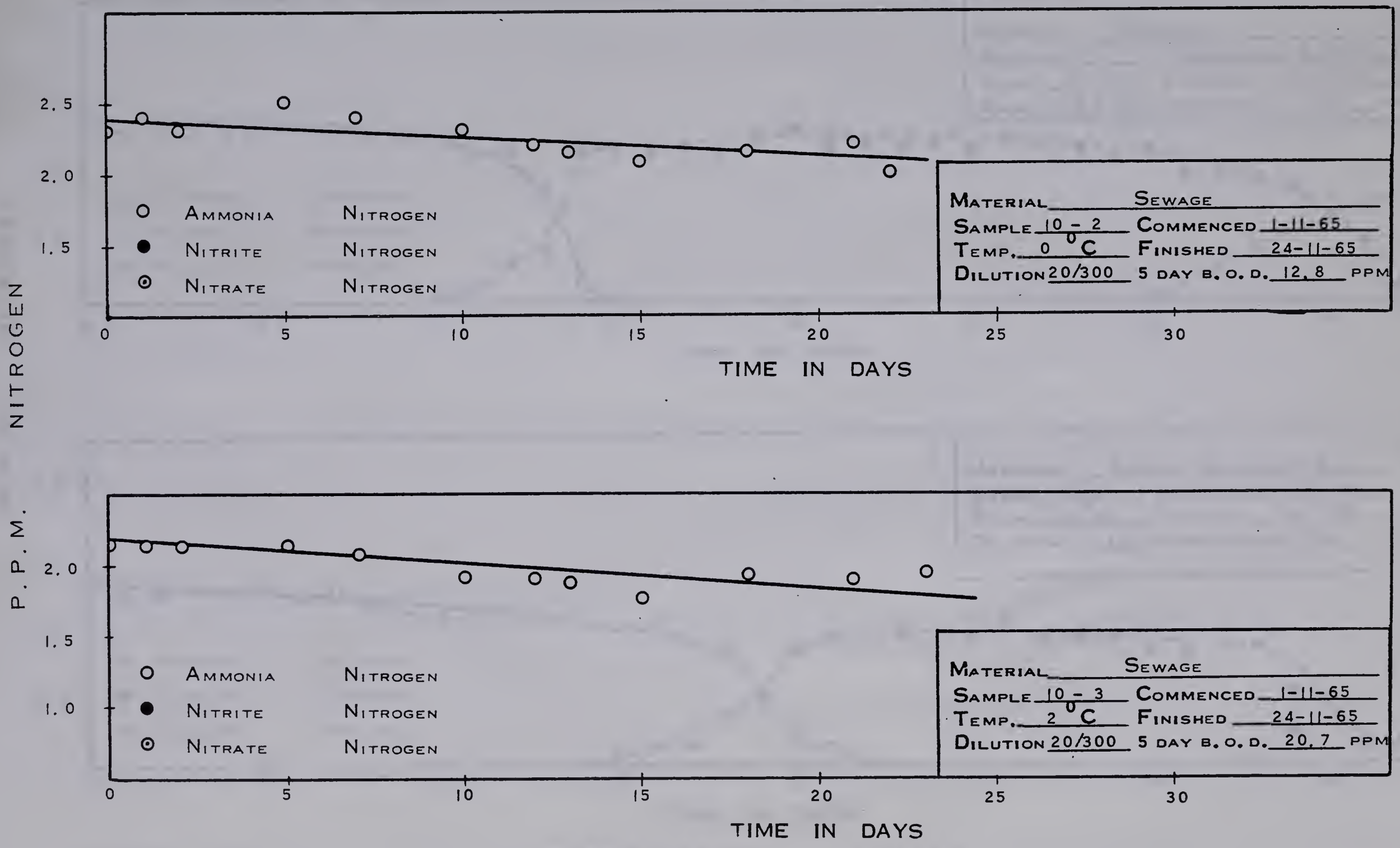
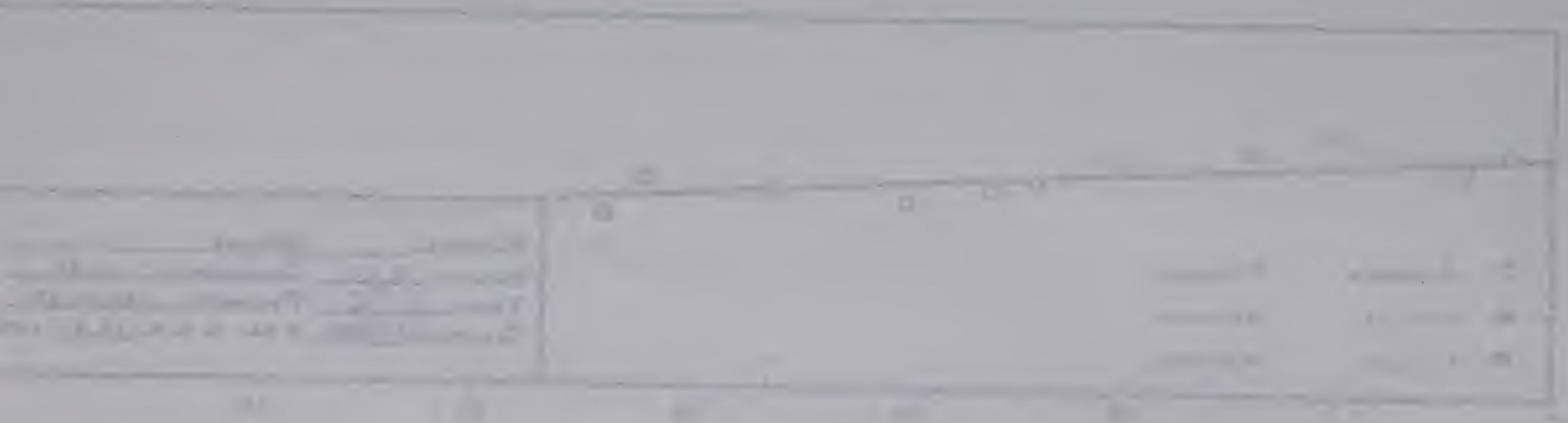
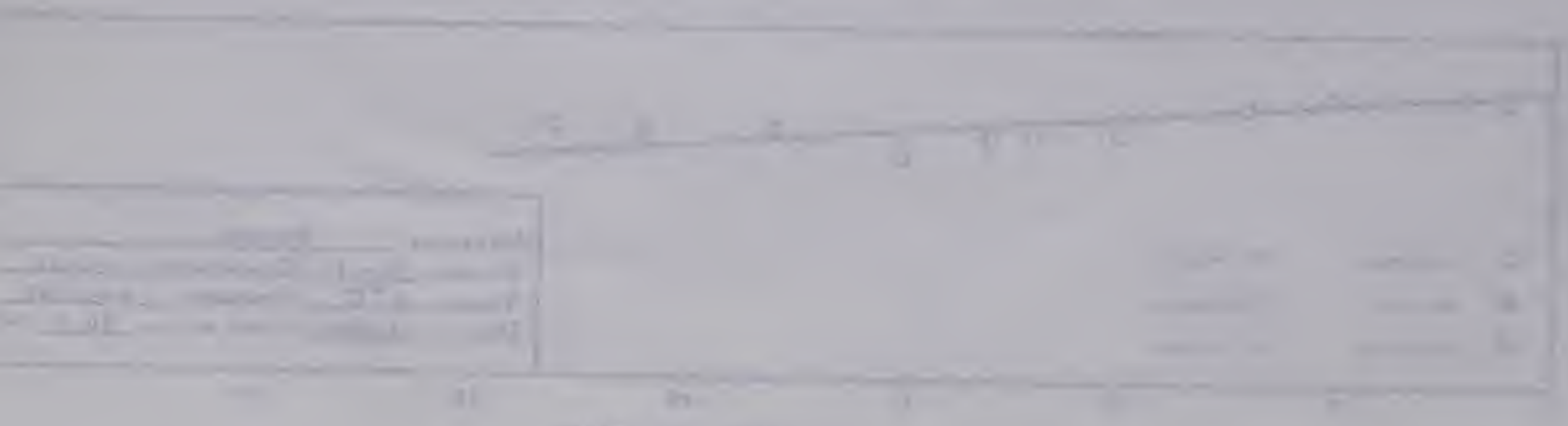


FIGURE: 4 - 54 NITRIFICATION STAGES





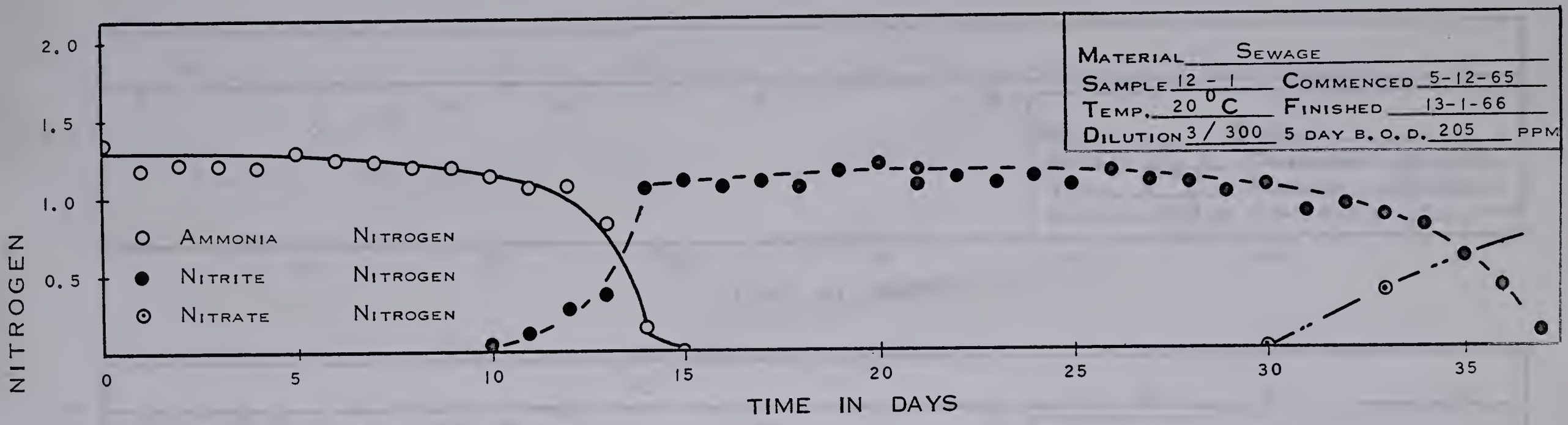
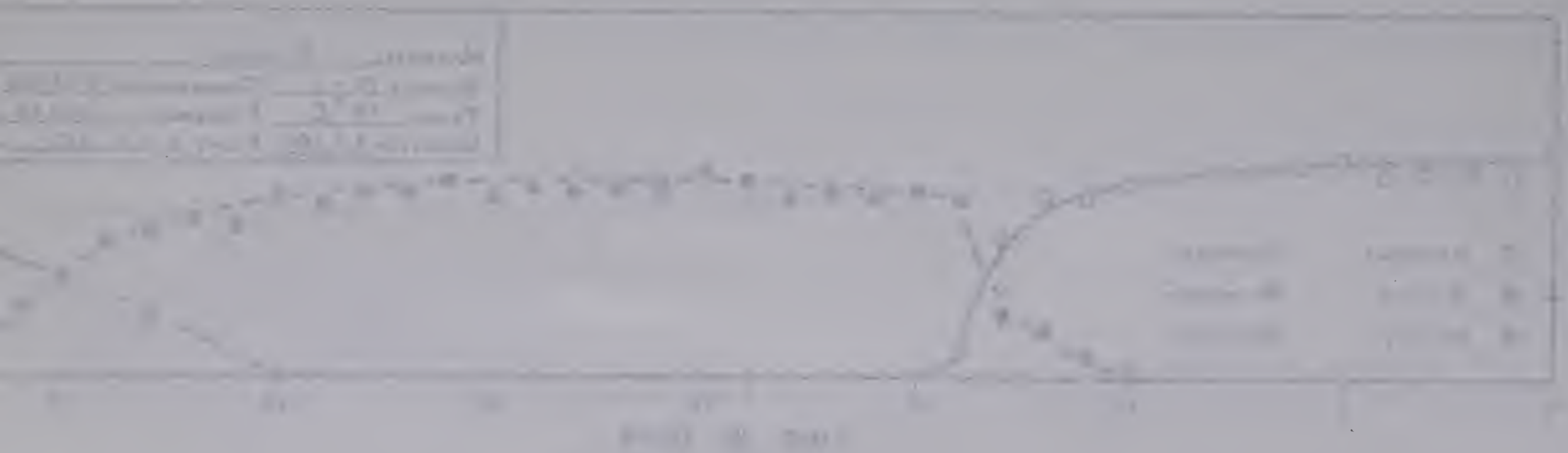


FIGURE: 4 - 55 NITRIFICATION STAGES





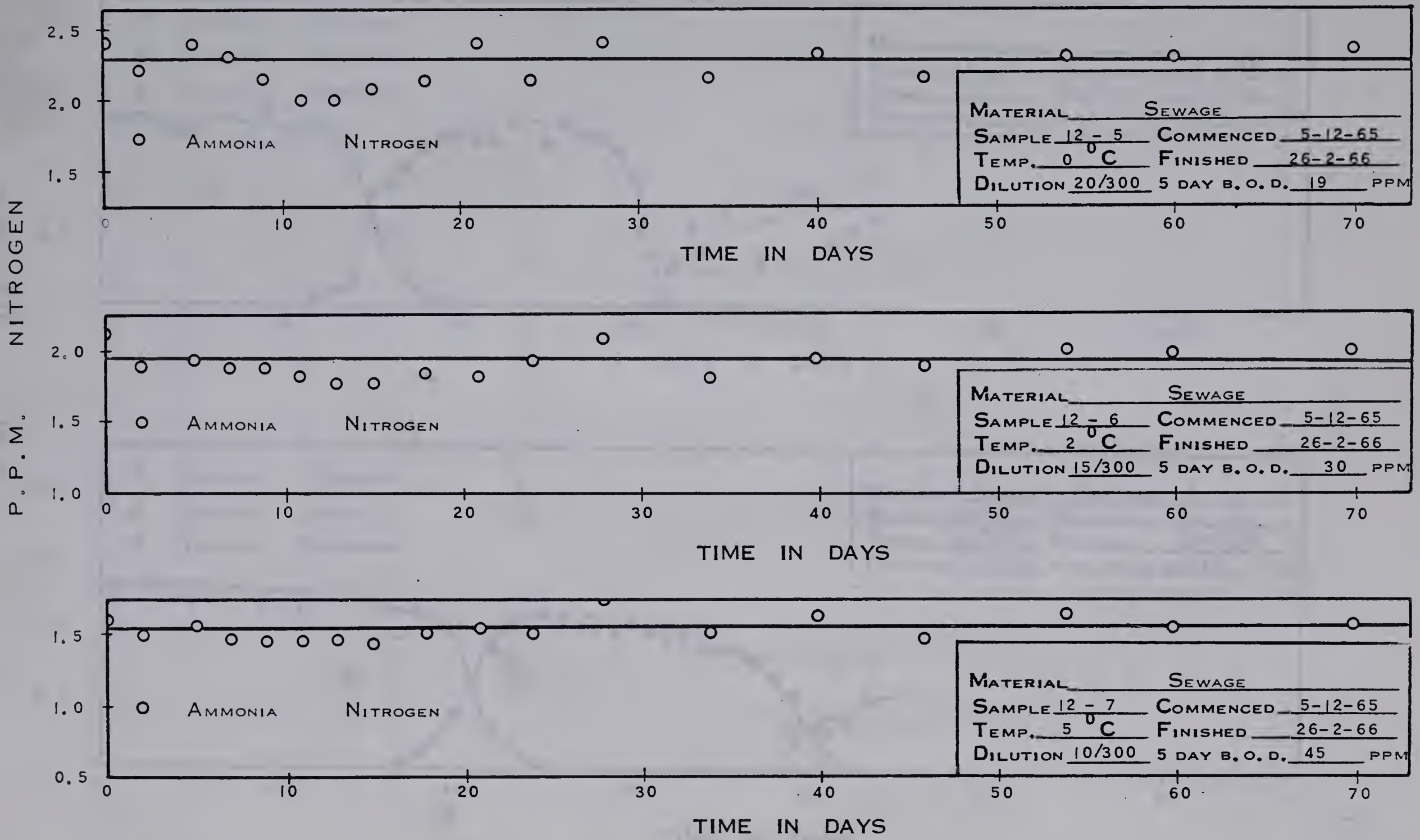


FIGURE: 4 - 56 NITRIFICATION STUDIES

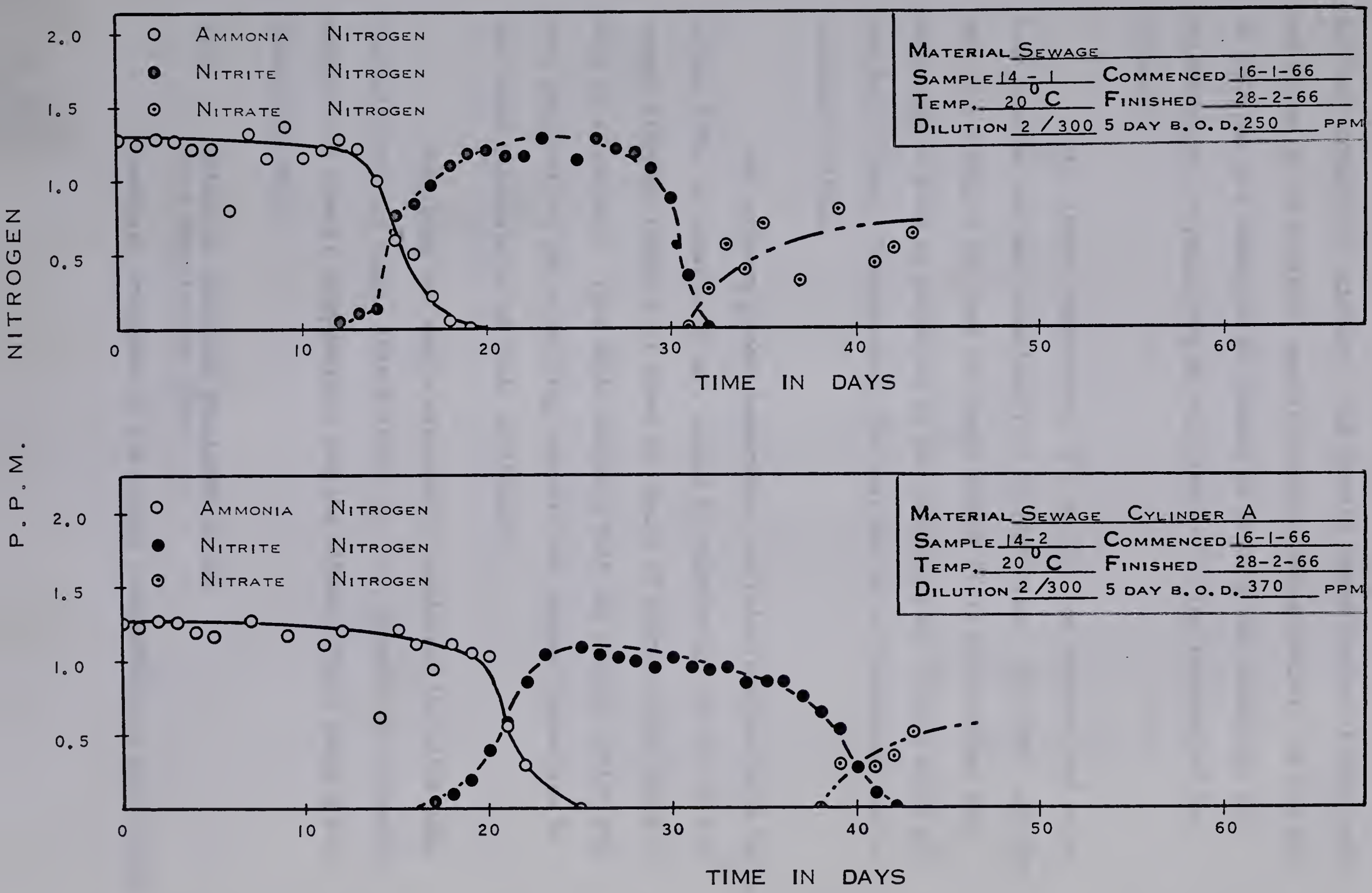
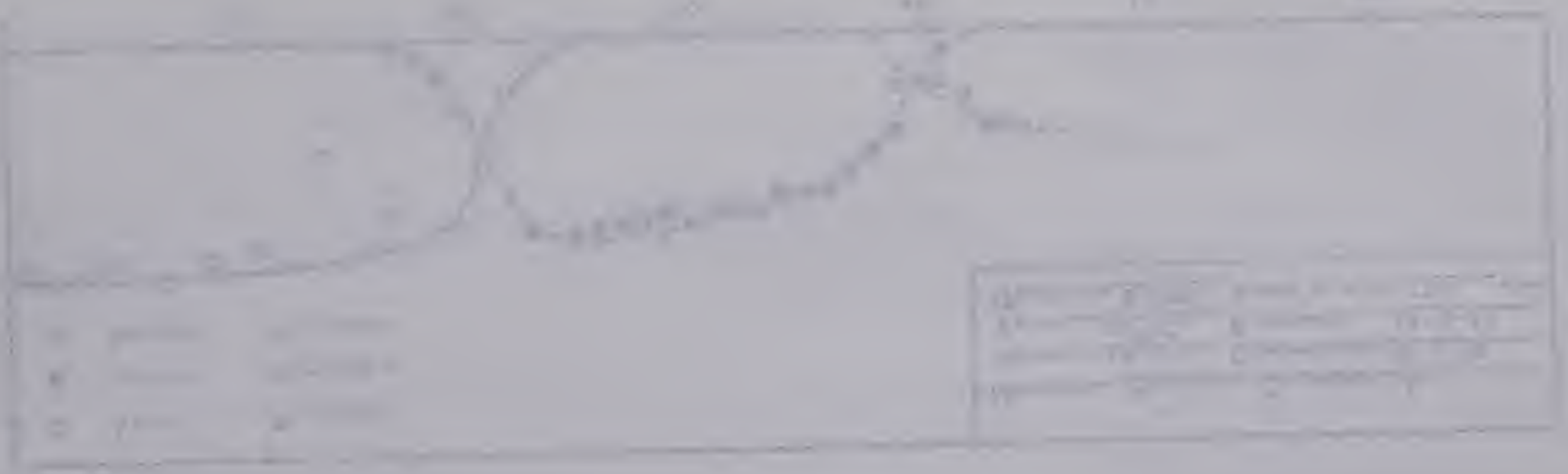


FIGURE: 4 - 57 NITRIFICATION STAGES





Maximum values of nitrites were obtained when all the ammonia had been completely oxidized. The nitrite concentration at this point was close to the original ammonia nitrogen concentration. By the 32nd to 38th day the oxidation of nitrite to nitrate had commenced, as evidenced by the rapid drop of the nitrite and the increase of the nitrate.

With lower temperatures, 0°C to 5°C, the standard and acidized samples indicate essentially no nitrification. However, near the end of a standard 5°C test on sewage (TABLE IV-9) the nitrites were beginning to form as indicated on the semi-log plot (FIGURE 4-13) of the B.O.D. data. Unfortunately the test had to be terminated due to incubator failure.

With optimum growth temperature for nitrifying bacteria being around 20°C, no growth, if any, should be expected in the 0°C to 5°C range, although FIGURE 4-13 shows the start of nitrification after 70 days of incubation. This would indicate that all organic matter had been oxidized and the nitrifying bacteria had adapted themselves to the lower temperatures of their environment.

Acidizing the sample effectively eliminated the nitrifying bacteria from the sample (TABLE IV-10, 11, 13), however it noticeably changed the rate of deoxygenation and the ultimate first stage B.O.D. (See TABLE IV-5).

IV-5 Effect of Secondary Treatment on the North Saskatchewan River

Secondary treatment of the sewage from Edmonton's main sewage

treatment plant, during the period of ice cover, is required (III-3) to reduce the oxygen demand on the river such that the dissolved oxygen depletion will not fall below the required level to maintain the normal aquatic biota. During the summer months there is continuous reaeration of the river water so that only primary sewage treatment is required (FIGURE 3-1). A change from primary to secondary sewage treatment reduced the B.O.D. curve as shown in FIGURE 4-58 and 59 for data given in TABLES IV-15 and 24.

As shown in TABLE IV-4, the secondary sewage treatment reduced the deoxygenation rate constant "k" for the river from 0.129 per day to 0.02 per day; and increased the ultimate first stage B.O.D. "L" from 4.79 to 9.8 p.p.m. (at 20°C). FIGURE 4-58 shows the values of "L" as 4.0 and 1.8 p.p.m. (for the river water) before and after the provision of secondary sewage treatment.

Using the calculated values of "k", a reduction of 83% is affected by the provision of secondary treatment, compared to a reduction of 86% if the "L" values from FIGURE 4-58 are used.

The calculated value of "k" obtained for after secondary sewage treatment influenced the ultimate first stage B.O.D. value "L" indicating a higher loading on the river than that indicated by plotting the data (Ludzack 1953). This information confirms that there is a discrepancy between the actual and calculated rate constants.

The effect of providing secondary sewage treatment at Edmonton on nitrification is given on FIGURES 4-58, 59 and 60. Nitrification

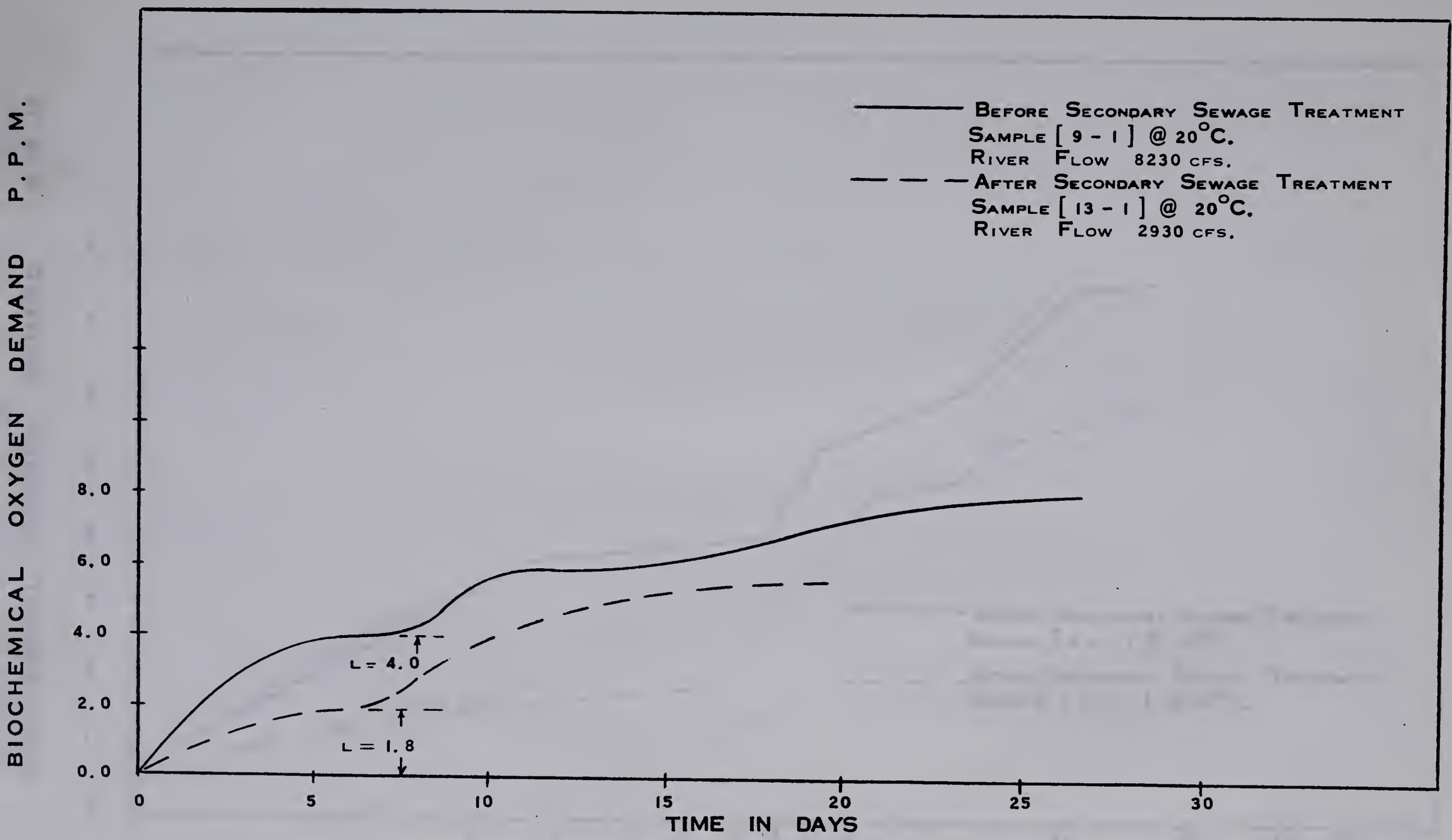
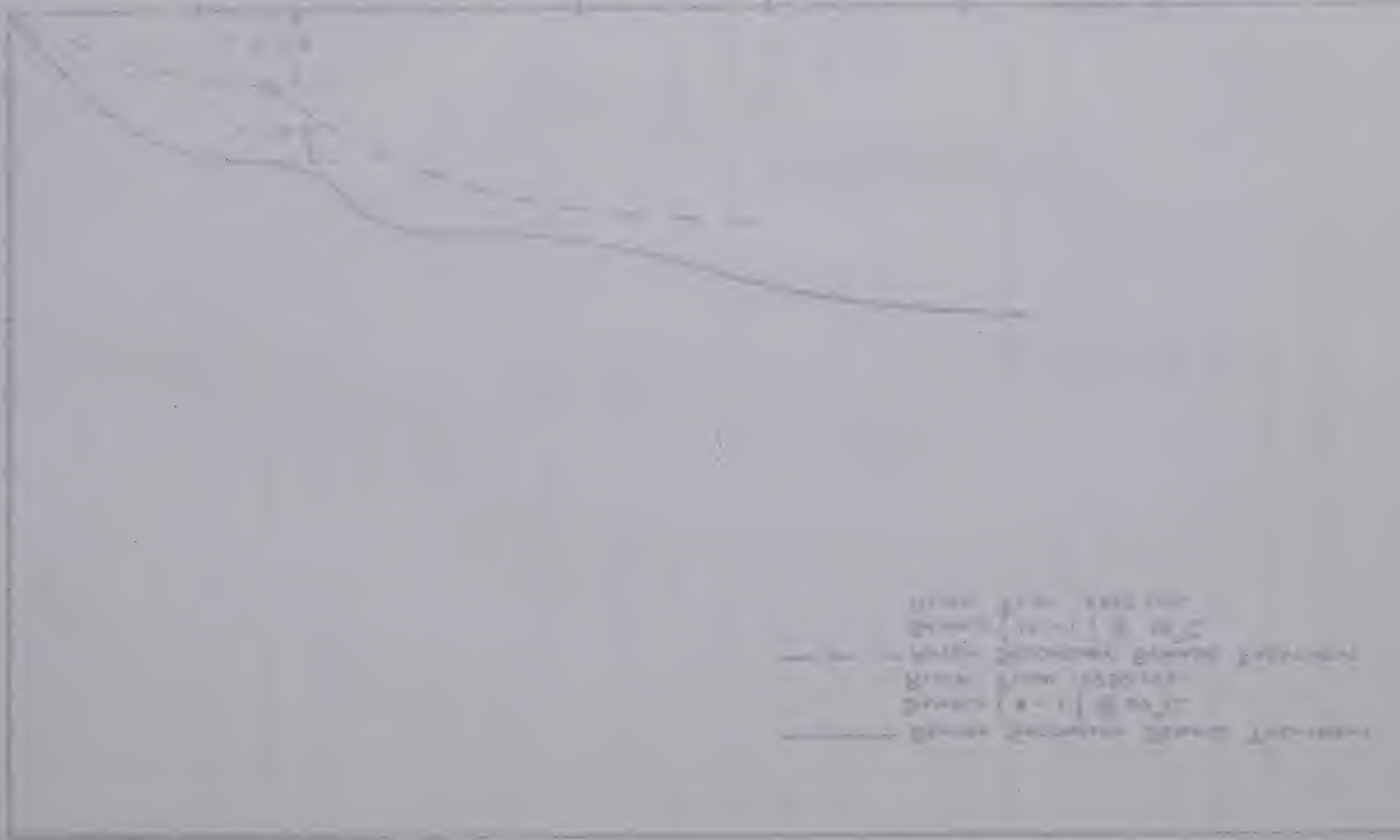


FIGURE: 4 - 58 B.O.D. CURVES FOR THE NORTH SASKATCHEWAN RIVER SAMPLE
— EFFECT OF TREATMENT —



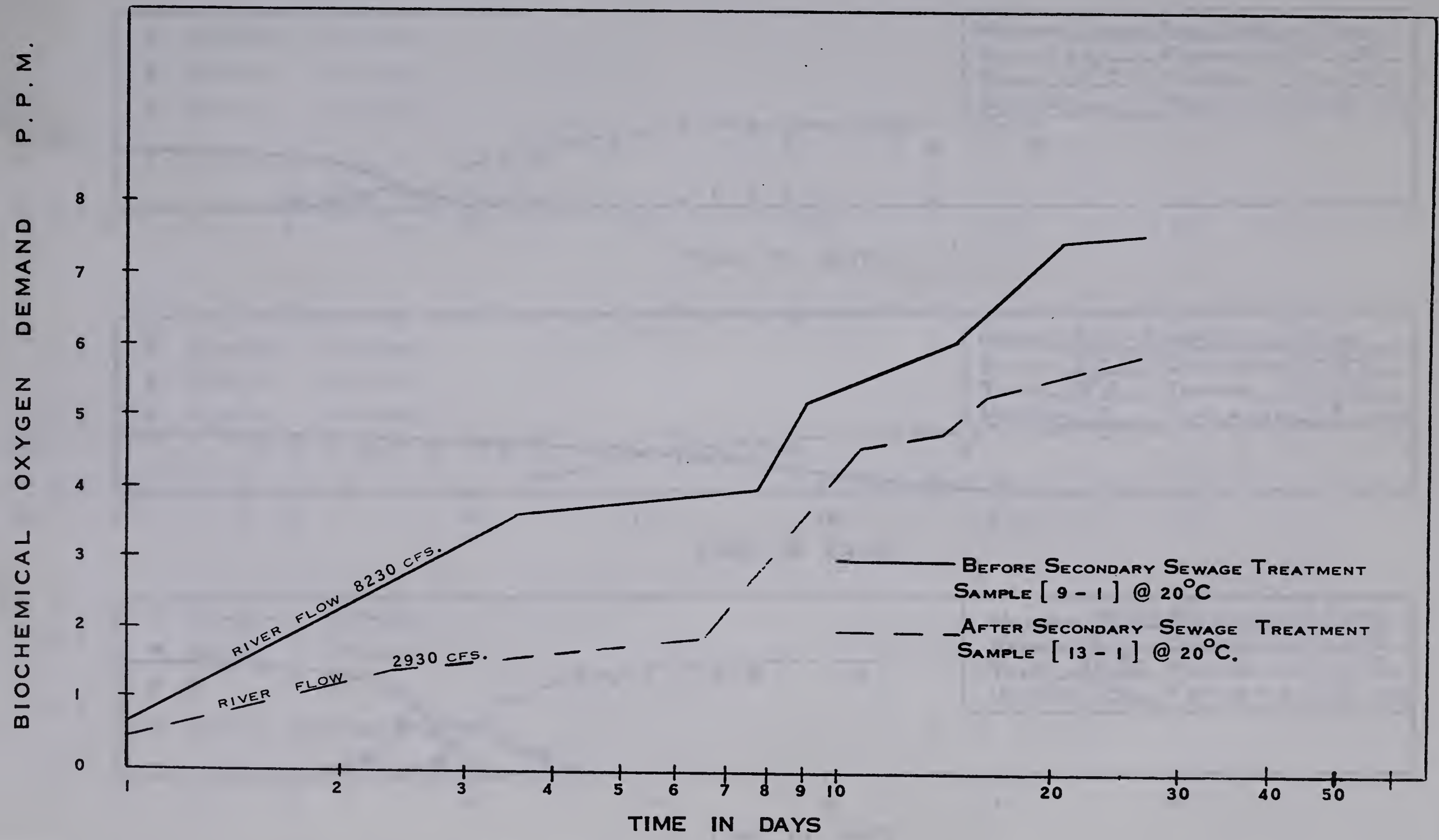
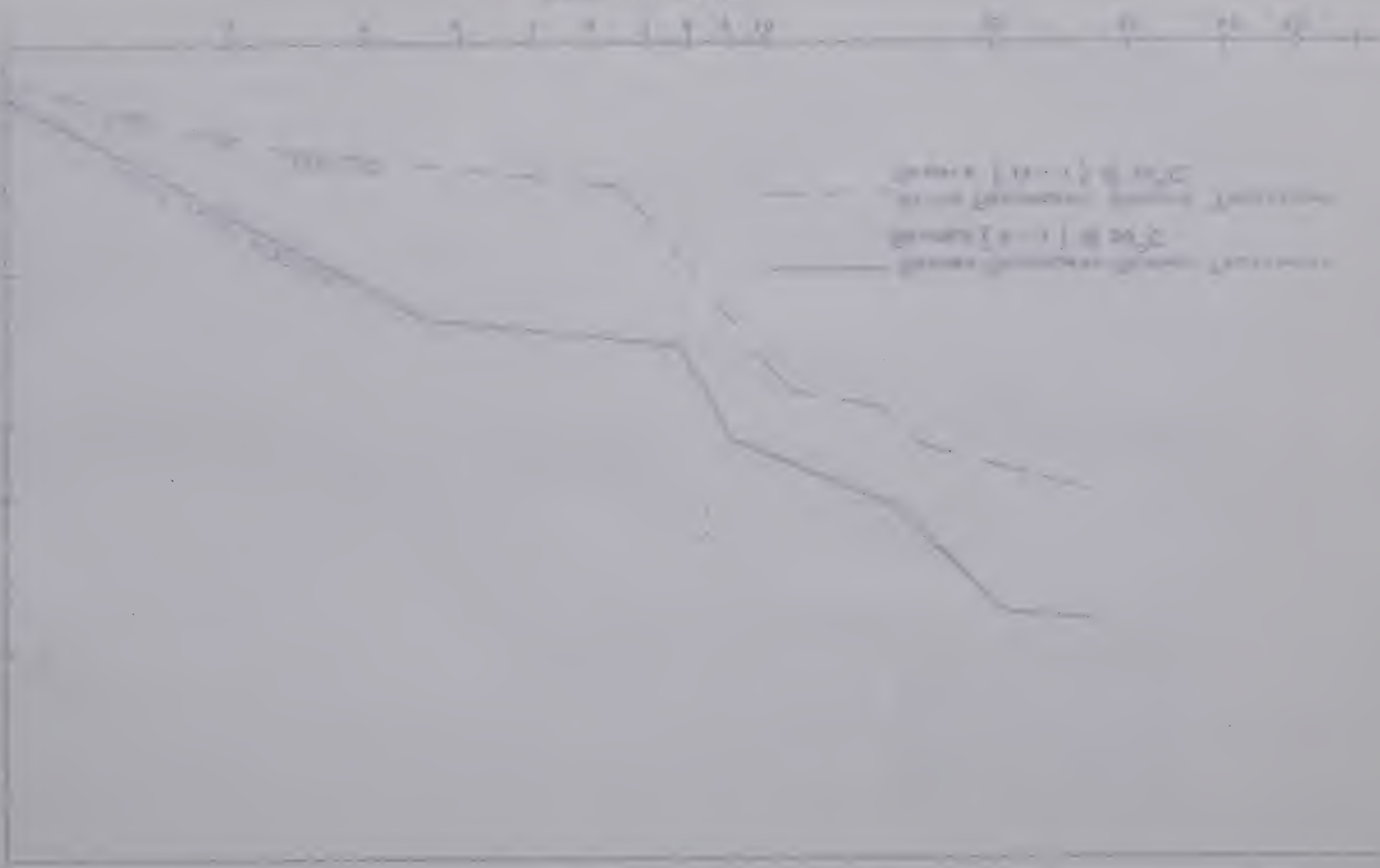


FIGURE: 4 - 59 B.O.D. CURVES FOR THE NORTH SASKATCHEWAN RIVER SAMPLE EFFECT OF TREATMENT



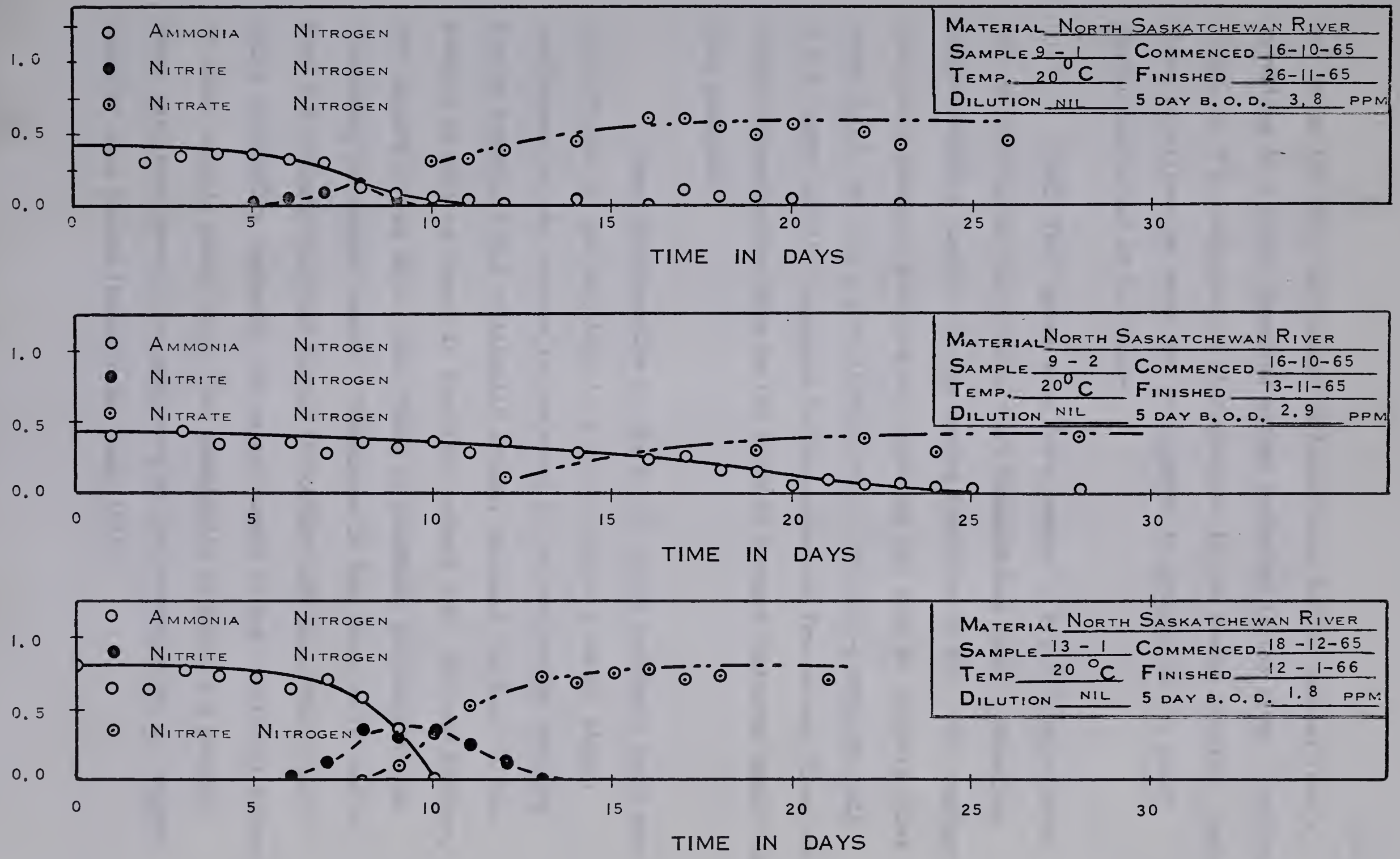


FIGURE: 4 - 60 NITRIFICATION STUDIES

was shown (at 20°C) to proceed at lower rates and to reduced levels, resulting in a lower dissolved oxygen depletion in the river. Previous tests, at 0°C, indicated no nitrification in the sewage samples, therefore, nitrification would not be expected to proceed in the river during the period of ice cover.

TABLE IV-27 gives data for a series of B.O.D.'s which were set up directly in the river at Fort Saskatchewan using a dissolved oxygen sampling bucket, and the sample incubated at 0°C. The deoxygenation rate constant obtained was 0.180 per day with an ultimate first stage B.O.D. of 1.22 p.p.m. (TABLE IV-4). FIGURE 1-2 compares this B.O.D. curve and its constants to those obtained from actual dissolved oxygen determinations made on the river at various distances downstream from Edmonton.

These discrepancies in the B.O.D. curve constants could possibly be due to the fact that in a B.O.D. bottle a small, closed environment exists whereas in the river it is continually changing. Bottom deposits being continually eroded, increase the load in suspension as well as change in the river contact bed. The new surface, now exposed to the water, will start to decompose aerobically thus increasing the oxygen demand. Turbulence in the river would tend to keep the bacteria and food supply in contact with each other, and would continually replenish the oxygen supply to any "bacterial slimes" or other aquatic plant life. The combination of these and possibly other variables have to be considered in the determination of "oxygen balance" in a stream (Edwards and Owens 1965).

IV-6 Investigations into a New Method of Conducting Long Term B.O.D.'s

The construction of Mylar bags in which long term B.O.D.'s could be run was unsuccessful. The problem arose in that the original material was too thin and fragile to handle without causing leaks. When heavier Mylar was used the heat sensitive tape, used in the fabrication of the bags, would not adequately seal the Mylar. No tests on the Mylar bags were completed to the five days without becoming contaminated.

If a medium grade Mylar was available (5 mls.) the heat sensitive tape may be adequate, and the material sufficiently thick to prevent leaks from occurring.

Results using the perspex cylinders were more encouraging. The piston for Cylinder "A" was first made with a rubber O-ring, however this was later replaced with a teflon O-ring. It was felt that the teflon would not have an oxygen demand in itself. The teflon O-ring, due to its low coefficient of friction, also facilitated the movement of the piston.

Various short term tests were conducted on the cylinder which proved the necessity of changes in the design. The data given in Chapter IV relating to the cylinder, was obtained after the improvements were made.

Two smaller cylinders, Cylinders "B" and "C", were also constructed. These were used to determine if seals other than the teflon O-ring would be satisfactory. Seals were made of teflon sheeting

0.125 inch thick. One seal was made such that it would turn upwards when inserted into the cylinder, and the other was made to act similar to pump leathers when inserted into the cylinder. Another seal was designed to stay perpendicular to the cylinder by cutting a shallow, circumferal grove in the edge of the teflon sheets. These methods originally appeared to provide adequate seals, but failed under test conditions by permitting contamination of the sample. Results of tests on these cylinders are not recorded.

To check the various materials used in the construction of the piston and cylinder, standard five day B.O.D. tests on sewage with chips of the various materials added to the bottles were conducted. In order that the sewage would be the same for all tests on the material, portions of the original sewage sample were frozen for use in later tests as outlined in A-3. Results of these tests are tabulated and averaged in TABLE IV-28 which indicated that the lucite chips in the bottles produced an average B.O.D. 21.1% higher; and the teflon chips produced an average B.O.D. 4.0% higher than the B.O.D. obtained using standard B.O.D. bottles.

TABLE IV-28 shows the effect of freezing on the B.O.D. of an unseeded sample. This would indicate that frozen sewage samples require seeding before running B.O.D.'s, as described by Morgan and Clark (1964).

Perspex is reportably inert to bacteria (TABLE III-3), therefore it was felt that surface area may be affecting the tests. In order to check the effect of surface area on B.O.D.'s, two sets

TABLE IV-28

SURVEY OF B.O.D.'s USING CHIPS OF CYLINDER MATERIAL

Date of Test	Standard B.O.D. *	Lucite Chips B.O.D.*	Lucite Chips %**	Teflon Chips B.O.D.*	Teflon Chips %**	Glass Beads B.O.D.*	Glass Beads %**	Comments
28/5/65	125 (i)							
16/7/65	96 (ii)	108	12.5					
22/7/65	131 (ii)	137	4.5					
19/8/65	122 (ii)	112	8.0	128	5.0			
31/8/65	88	96	7.5	89	1.0			
11/10/65	106 (ii)	111	5.0	105	1.0			
14/11/65	108 (ii)	129	19.0	114	5.0			
12/2/66	140 (ii)	180	28.0	151	8.0	288	106	75 mls. of beads
28/2/66	37 (ii)	159	430	107	289	241	650	75 mls. of beads (not considered in average)
	113	128	12.1	117	4.0	266	378	AVERAGE VALUES

* five day 20°C - B.O.D. in p.p.m.

** % greater than B.O.D.*

i fresh sewage frozen for rest of tests

ii using frozen sewage from i

of B.O.D.'s with sewage and 75 mls. of glass beads were set up. These results (TABLE IV-28) showed extremely high B.O.D.'s over that of the standard test set up at the same time and from the same mixture of sewage and dilution water. Additional tests were conducted (TABLES IV-29 and 30) to either prove or disprove the surface area effect on B.O.D. levels. TABLE IV-29 gives varying effects for B.O.D.'s set up with different volumes of beads and TABLE IV-30 shows essentially the same B.O.D.'s for various volumes of beads in the bottle. From these tests it was concluded that surface area did not affect the B.O.D., however Edwards and Owens (1965) have reported that surface area does affect the B.O.D.

With the perspex and teflon being inert to bacterial attack, (very little surface contact between the teflon and sample), and surface area apparently not affecting the B.O.D., no theories have been proposed to account for the high oxygen demand incurred when these materials were present in the B.O.D. bottle.

Results of test runs on the cylinder for dissolved oxygen depletion, using distilled water, showed losses of up to 1.0 p.p.m. dissolved oxygen within a five day period; whereas in the B.O.D. bottles, filled from the cylinder immediately after it was on test, had a dissolved oxygen depletion of 0.5 p.p.m. in six days.

The cylinder was then checked using sewage as per TABLES IV-16, 20, and 26. B.O.D. curve constants for the cylinders, using sewage and incubated at 20°C, indicate a lower "k" value and a higher "L" value (see TABLE IV-2 and 5) when using river water in the

TABLE IV-29

EFFECT OF GLASS BEADS ON THE FIVE DAY B.O.D.

Sample: 17-1
Temperature: 20°C
Date of Test: 6/3/66

Material: Sewage #3 Plant
Dilution: 4/300

Mls. of Beads	B.O.D. p.p.m.	% of Standard
0	98	100
15	124	127
30	94	96
45	98	100
60	101	103
75	109	111

1 ml. of beads = 0.29 square inches surface area

TABLE IV-30

EFFECT OF GLASS BEADS ON FIVE DAY B.O.D. TEST

Sample: 18-1
Temperature: 20°C
Date of Test: 19/3/66

Material: Sewage
#3 Plant
Dilution: 6/300

Mls. of Beads	B.O.D. p.p.m.	% of Standard
0	150	100.0
20	151	100.5
40	147	98.0
60	149	99.5

1 ml. of beads = 0.29 square inches surface area

cylinder, at 20°C, "k" was lower by 27.1% and "L" was 2.24% higher than those obtained using standard B.O.D. bottles.

On the three long term tests conducted in the cylinder, lower deoxygenation rates and higher ultimate first stage B.O.D. values were obtained. Sufficient information has not been obtained on the cylinder to formulate definite conclusions on the suitability of the cylinder for long term studies.

CHAPTER V

SUMMARY AND CONCLUSIONS

A review of the B.O.D. theory has been given showing the effect of lower temperatures on the B.O.D. curve constants, deoxygenation rate constant "k" and ultimate first stage B.O.D. "L"; on the various nitrification stages, ammonia, nitrite and nitrate; and on the effect of acidizing a sewage sample. A brief investigation into the affect on the North Saskatchewan River of increasing the degree of sewage treatment at Edmonton has been provided. Two different types of material were investigated for the construction of containers for use in conducting long term B.O.D. studies.

The deoxygenation rate constant "k" for domestic sewage tested at 20°C was found to be 0.139 per day with an ultimate first stage B.O.D. range of 135 to 290 p.p.m. With a decrease in temperature the rate of deoxygenation decreased from 0.139 per day at 20°C to 0.043 per day at 0°C; the ultimate first stage B.O.D. "L" was shown to decrease with a decrease in temperature, however the calculated values of "L" varied over a wide range.

A plot of "k" versus temperature was obtained which gives the rate of deoxygenation constant "k" for a temperature range of 0°C to 20°C for a domestic sewage.

Further studies would be desirable on different domestic sewages and at different temperatures to fill the balance of the "k" versus "t" curve obtained - FIGURE 4-4. When low values of "k" occur Thomas' method of determining "k" and "L" should not be used as "L" is greatly influenced by "k".

The Activation Energy value "E" for use in converting the deoxygenation rate constant, "k", at one temperature to "k" at another temperature was found to be 26,800 calories for use in the Arrhenius Equation. This value of "E" is accurate within a temperature range of 0°C to 5°C.

Nitrification studies indicated a nitrite period which lasted ten to fifteen days at 20°C and was absent at the lower temperatures. No nitrification was found to occur at temperatures below 5°C within 20 days. Acidizing a sewage sample effectively prevented nitrification, however it also affected the value of the deoxygenation rate constant "k" and the ultimate first stage B.O.D. "L".

B.O.D. studies on the river confirm that the rate constants obtained by the bottle test do not agree with actual conditions occurring in a river. Secondary sewage treatment was found to generally reduce the B.O.D. curve over that obtained when only primary treatment was effective on the sewage before being discharged to the river.

For running long term B.O.D.'s the use of Mylar bags proved unsuitable, however if a medium weight material was obtained or a manufactured Mylar bag was available the study should be reviewed.

The perspex cylinder as a container proved very satisfactory, however, different values of "k" and "L" were obtained by the use of these cylinders over the standard bottle tests. No explanation of this discrepancy has been offered by the author.

The thesis does review the theory relevant to the biochemical oxygen demand as well as providing additional information on the B.O.D. curve in relation to how it is affected by lower temperatures. Further work on the usefulness of the perspex cylinder would be desirable as it provides a very simplified method of running long term B.O.D.'s, however an explanation for the difference in dissolved oxygen levels and B.O.D. curve constants is still required.

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APPENDIX A

PROCEDURES AND METHODS

APPENDIX A

PROCEDURES AND METHODS

A-1 Test Procedures

The dilution water for B.O.D.'s was prepared and checked as per Standard Methods (1960). Before setting up any test, the distilled water was first brought to the temperature of the test. It was then aerated with filtered air. A carborundum diffuser was used to increase the oxygen transfer rate.

Once the distilled water was at the test temperature, the correct volume was transfered to a container sufficiently large to hold all the water and sewage for that series of tests. The sewage and nutrients were then added to the water. After an additional five minutes aeration the sample was allowed to settle for 20 - 30 minutes to allow the air bubbles to escape.

Before filling the bottles, and after the 20 - 30 minute settling time, the container was gently stirred with the syphon rod and filling commenced.

The bottles which had previously been arranged in rows were filled a row at a time. Periodically the sample was stirred to keep any solids evenly dispersed.

Shortly after filling, each bottle was tapped with the stopper to facilitate the release of any trapped air. Once filling was completed the bottles were tapped, inspected for bubbles, and stoppered in the same order that they were filled.

The three bottles for the original dissolved oxygen determinations were taken from the middle and each end of the series. Two samples were taken for daily B.O.D.'s, one from each end and the nitrification test sample from the middle of the series.

When the dissolved oxygen became low the bottles were drained into a large container and aerated for approximately a half hour. After aerating the same bottles were filled following the preceding method.

A sufficient quantity of distilled water, nutrient, and sewage were mixed in one batch to complete all the required tests being conducted at one temperature of the series. The same sewage sample was used for all the tests in any one series.

Ammonia nitrogen was determined as per Standard Methods (1960) by the Direct Nesslerization Method. This method was chosen over the distillation method as the samples generally obtained in excess of 0.1 p.p.m. ammonia (except after nitrification has started) and the test procedure itself is relatively simple and not too time consuming.

An ammonia "blank" was set up for each ammonia determination using ammonia free water. Before running the test all pipettes and nessler tubes were rinsed in ammonia free water to remove any traces of ammonia. The nessler tubes used for the samples were further rinsed out with a portion of the samples before testing.

Determinations of ammonia nitrogen were made with the use of

a Spectronic 20 with a 1 cm. light path at 410 mμ

Nitrite nitrogen was determined as per Standard Methods (1960). A distilled water blank was used. Determinations of nitrite nitrogen were made with the Spectronic 20 and a light path of 520 mμ

Nitrate nitrogen was determined as per Standard Methods (1960). All samples were treated with 1 ml aluminum suspension and double filtered before the test was commenced. The sample was allowed to evaporate overnight (protection against contamination was provided by partially covering) and finished the next day. A distilled water "blank" was set up for each set of tests. The distilled water was not treated with alum nor filtered. Determinations were made on a Spectronic 20 with a light path of 400 mμ

A-2 Incubators

Early in the testing program it was found that small or makeshift incubators would not provide the necessary control for conducting the tests. Incubators in which the large volume of dilution water could be aerated at a set temperature, which contained adequate shelf space to store up to 200 bottles and still provide working area, were required.

A 2" x 2" fir studding, $\frac{1}{4}$" plywood box was constructed 8 feet high, 16 feet long and 8 feet deep. This was then divided into three 5.3 foot sections thus making three 8' x 5.3' incubators. The inside of each incubator was lined with three $1\frac{1}{4}$" thick layers of styrofoam (K factor 0.24). The 2' x 4' sheets of styrofoam in-

sulation was staggered to ensure good insulation characteristics. A work bench was installed along one end of the incubator and an insulated freezer door installed on the opposite end. Thirty inch shelves were installed along one side of the incubator for storage of B.O.D. bottles. Compressed air, electricity, water and sink were installed in each unit.

Room temperatures were such that only cooling of the incubators was required. A water cooled one H.P. Model #WB1T16WT Tecumsek freezing unit was installed. Freon 12 was utilized as the refrigerant. Each incubator was fitted with a Model #LSC-1 Recold unit which was wired to run steady thus maintaining the air in continuous circulation and was equipped with a separate Ranco #1410 thermostat.

This type of temperature control has proven to be completely automatic and generally trouble free.

An automatic defrost (870 watt heater) was installed in the zero ^{o}C incubator to prevent possible freezing of the Recold unit, enabling this incubator to be used at temperatures near or below $0^{o}C$. The other incubator should be maintained at temperatures above $0^{o}C$.

Thermometers were installed in corked, water filled bottles to record the water temperatures. Copper (+) Constantan (-) thermacouples were also installed in the water to record the temperature. The thermacouple temperature was recorded on a Honnywell Brown Electronik Potentriometer Model #153X64P6-X-42A1 with a range of $0^{o}F$ to $150^{o}F$.

Bottle temperature variance in the $32^{o}F$ incubator was

±0.2°F, with a low of 32.0°F and a high of 32.4°F (32.2°F average). This was just sufficiently above freezing to prevent ice formation in the B.O.D. bottles. The thermostat operated on an 18 minute cycle.

Exceptionally close control was obtained in the 35.6°F (2°C) as the recorder showed a straight line. Here the thermostate operated on a 19 minute cycle.

Control of the 20°C incubator was the most difficult. The room temperature in which the incubators were constructed was controlled to approximately 24°C. Since the incubator thermostat only operated on a five hour cycle a water temperature variance of ±0.75°F occurred. A 250 watt chromolox-strip heater HPT512 (which provides 14 watts/sq. inch) was installed behind the Recold unit. This increased the number of cycles to one every 28 minutes, which affected a temperature control to ±0.25°F.

A-3 Samples

Sewage used in all tests, other than the North Saskatchewan River samples, were obtained when required from the City of Edmonton #3 Sewage Treatment Plant located east of the 105th Street bridge.

The plant is a conventional primary sewage treatment plant with sludge digestion. It receives two $2\frac{1}{2}$ M.I.G.P.D. of sewage from an estimated contributing population of 50,000. The area involved is mainly residential. The sewage at the plant can be classified as a fresh domestic sewage. Analyses (Alberta Department of Public Health) is reported in TABLE A-1.

TABLE A-1

EDMONTON #3 SEWAGE TREATMENT PLANT

24 Hour Composite Samples — Final Effluent

Date	March 25/65	Oct.21/65	Nov.9/65	Dec.8/65	Ave.
B.O.D.*	171	143	208	151	168
pH	7.6	7.35	6.9	7.6	7.36
Alk. m.p. ppm	176	155	150	150	157
p.p. ppm					
Phenols ppb	250	200	100	81	157
Chloride ppm	35	20	70	28	38
Oils & grease ppm		22	24	24	23
Total solids ppm					
total	462	380	457	420	429
volatile	183	150	185	160	169
fixed	279	230	272	260	260
Suspended solids ppm					
total	116	92	122	152	120
suspended	96	88	100	108	98
fixed	20	4	22	44	22
NH.N ppm	29.5	20.6	23.5	26	24.9

* ppm 20°C, five day B.O.D. (not seeded)

Samples were obtained from the last effluent channel of the settling tank and transported directly to the laboratory. They were then allowed to settle in an open jar for approximately three hours. The clear supernatant was syphoned off and filtered through glass wool before use. In any series of tests the sewage sample was prepared in this manner such that all phases or tests of the series would be conducted on the same sewage sample.

The majority of the samples used throughout the test period to check the various types of material used in the construction of the cylinder for their five day B.O.D. demand, were obtained on May 27, 1965 and treated in the aforementioned manner before being placed in a commercial deep freeze for storage. When required for use they were allowed to thaw out in a warm water bath, until all the ice had melted, and the test set up as in A-1. In setting up these tests the sewage was added to the dilution water, mixed, allowed to settle and then the bottles filled. One set of bottles were filled before the next set to help eliminate differences which may be incurred during filling.

The North Saskatchewan River samples were obtained from the raw water supply line at the Sherrit Gordon Plant in Fort Saskatchewan. Sherrit Gordon is located approximately 22 river miles downstream from Edmonton. Twenty-four hour composite samples were obtained by collecting the water at a steady rate of 50 mls./min. At the end of the sampling period the sample was well mixed and the required quantity removed and transported directly to the laboratory and tested.

One set of river samples were set up in the river using a dissolved oxygen sampling bucket. These samples were then incubated at 0°C.

A-4 Construction and Use of Mylar Bags

The bags were made by cutting out a double pattern such that when it was cut only the sides and the top required heat sealing. Mylar is joined by using a heat sensitive type Mylar tape. Corners of the bags were hard to seal, however this was overcome by providing a large overlap of the sealing tape. After successfully air testing the bags, a sewage and dilution water mixture was siphoned into the bottom of the bag in such a fashion that air was excluded from the bag as it filled. During filling, the bag was kept in the water bath to provide support for the bag.

Once the bag was filled with the sample it was squeezed to force any air bubbles out. A sample was then siphoned into the bottom of a 50 ml. bottle for dissolved oxygen determinations. The bottle was allowed to overflow it's volume once to ensure that air was not introduced during sampling.

After filling and sampling, the glass tubing was withdrawn from the long neck of the bag keeping the bag and most of the neck under water. The neck was then folded, under water, and clamped. This method efficiently prevented air getting into the bag.

For sampling the reverse procedure was followed only allowing a portion of the neck out of water at any one time.

A check on the bag method was obtained by setting up standard B.O.D. bottles from the same mixture and incubating these in an aerated, constant temperature water bath. Any changes in temperatures therefore would affect both the bag and the bottles equally.

The first bags were made of .0005 inches Mylar, since it was readily available. However, the bags were so light they required continual patching and it was impossible to run a test.

The second set of bags were made of 0.01 inches Mylar. This thickness of material is semi-rigged and is only translucent. In the construction of the bags all seams were double or triple taped and heat sealed. When the bags bent near the seam, the heat seal would not hold thus permitting contamination of the sample. Although several tests were conducted for various periods, a five day test could not be obtained.

Use of Mylar bags was discontinued at this stage.

A-5 Use of Perspex Cylinder

Construction details for the cylinder are given in Appendix "C".

Before using the cylinder for a test it was washed with a detergent, rinsed with hot tap water, acidized with chromic acid, rinsed in tap water and then thoroughly rinsed with distilled water. After draining the cylinder, the sample as prepared for setting up B.O.D.'s (A-1) was siphoned into the cylinder through the bottom opening.

When filled the bottom sampling line was clamped, and the piston pushed down to the water surface forcing some sample out of the piston air line. This valve was then clamped such that water was trapped in the line. The cylinder was then inverted and the bottom sample line opened by forcing the piston into the cylinder. All the air was thus excluded from the cylinder and sample line. The sample line was then clamped and the cylinder upright ed.

A screw-clamp was used to push the piston into the cylinder. Although the piston was free enough to allow a sample to be obtained from the bottom sampling line, a slight pressure was maintained on the piston to prevent any possibility of the water seal (on top of the piston) water contaminating the sample.

Ground glass stoppered bottles (150 ml.) were used for the dissolved oxygen determination. These bottles were filled from the bottom and were allowed to overflow their volume at least once.

The overflow water was collected in a clean beaker, providing a sample for nitrite and nitrate determination. For ammonia determinations 75 ml. ground glass stoppered bottles, which were previously rinsed in ammonia free water, were filled directly from the cylinder sampling tube taking care to prevent aeration of the sample.

Aeration of the sample when required was accomplished by opening the piston air line and raising the piston approximately two inches. Filtered air was then introduced through the bottom sample

line. After aeration, the same method of removing the air from the cylinder was employed.

A-6 Limitation of Investigation

The early stages of the study were greatly limited by the lack of facilities, mainly incubator space and B.O.D. bottles. The time required to run one long term, low temperature test was also a major consideration in limiting the research.

APPENDIX B

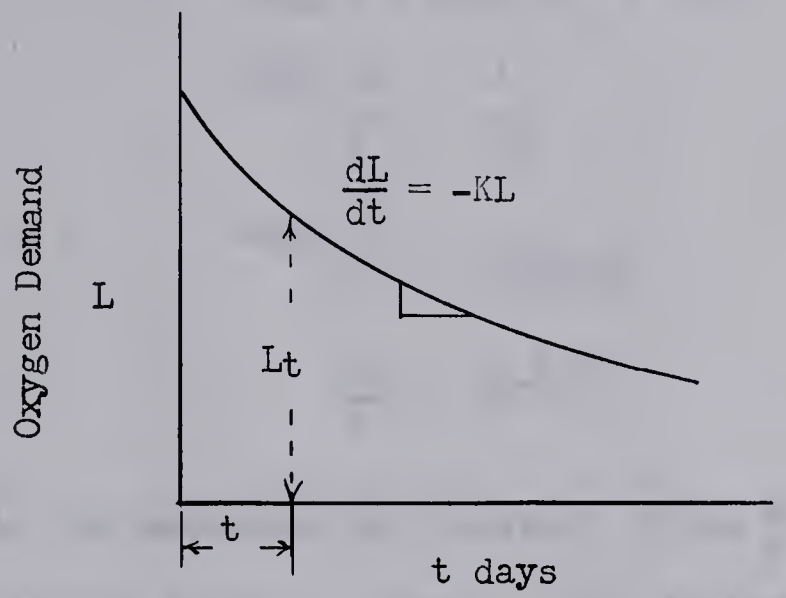
DEVELOPMENT OF

THE MONOMOLECULAR EQUATION

APPENDIX B

DEVELOPMENT OF THE MONOMOLECULAR EQUATION

Steel (1960) states that "the rate of biochemical oxidation of organic matter is proportional to the remaining concentration of the unoxidized substance, measured in terms of oxidizability". This relationship is shown graphically below.



where: "L" is the oxygen demand in p.p.m. at time "t" = 0 days and is the first stage demand (ultimate first stage B.O.D.)

"L_t" is the remaining oxygen demand at the end of any time "t" days

"K" is a constant associated with days and temperature and determined experimentally.

In the differential form

$$\frac{dL}{dt} = -KL \qquad \text{Equation 1}$$



or

$$\frac{dL}{L} = Kdt$$

Integrating

$$\text{Log}_e L_t = -Kt + C \qquad \text{Equation 2}$$

$$C = \log_e L_t + Kt$$

when $t = 0$, $L_t = L$, and $C = \log_e L$ substituting in equation 2 yields:

$$\text{Log}_e L - \text{Log}_e L_t = Kt$$

$$\text{Log}_e \frac{L_t}{L} = \frac{1}{Kt}$$

$$\text{Log}_{10} \frac{L_t}{L} = \frac{1}{0.434\ Kt} \qquad \text{Equation 3}$$

whence

$$\frac{L_t}{L} = 10^{-K_1 t} \qquad \text{Equation 4}$$

K_1 is the deoxygenation constant. Since $\frac{L_t}{L}$ is the remaining fraction of oxidizable matter, then $(1 - \frac{L_t}{L})$ is the fraction oxidized in "t" days. If y = amount oxidized in "t" days

$$y = (1 - \frac{L_t}{L})\ L$$

or

$$\frac{L_t}{L} = 1 - \frac{y}{L}$$

Substituting in equation 4

$$1 - \frac{y}{L} = 10^{-K_1 t}$$

or

$$y = L(1-10^{-K_1 t}) \qquad \text{Equation 5}$$

where K is the rate of deoxygenation constant (related to a base e)

k = 0.434 K (related to a base 10)

L = ultimate first stage B.O.D.

y = B.O.D. at time "t"

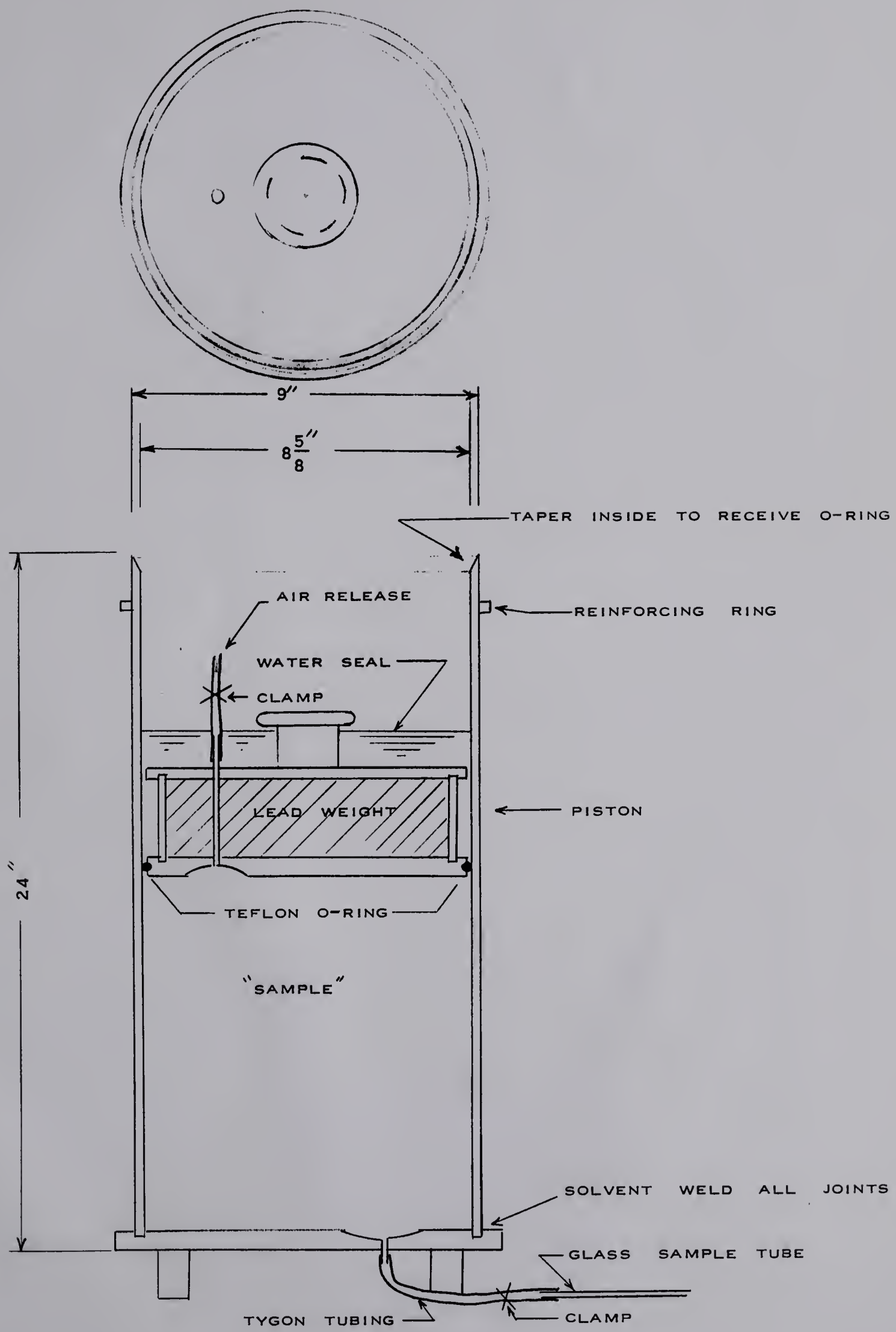
Practical evaluation of the equation 5 is complicated in that L and k are usually unknown. Thomas' (1950) method as used is one method for determining L and k.

APPENDIX C

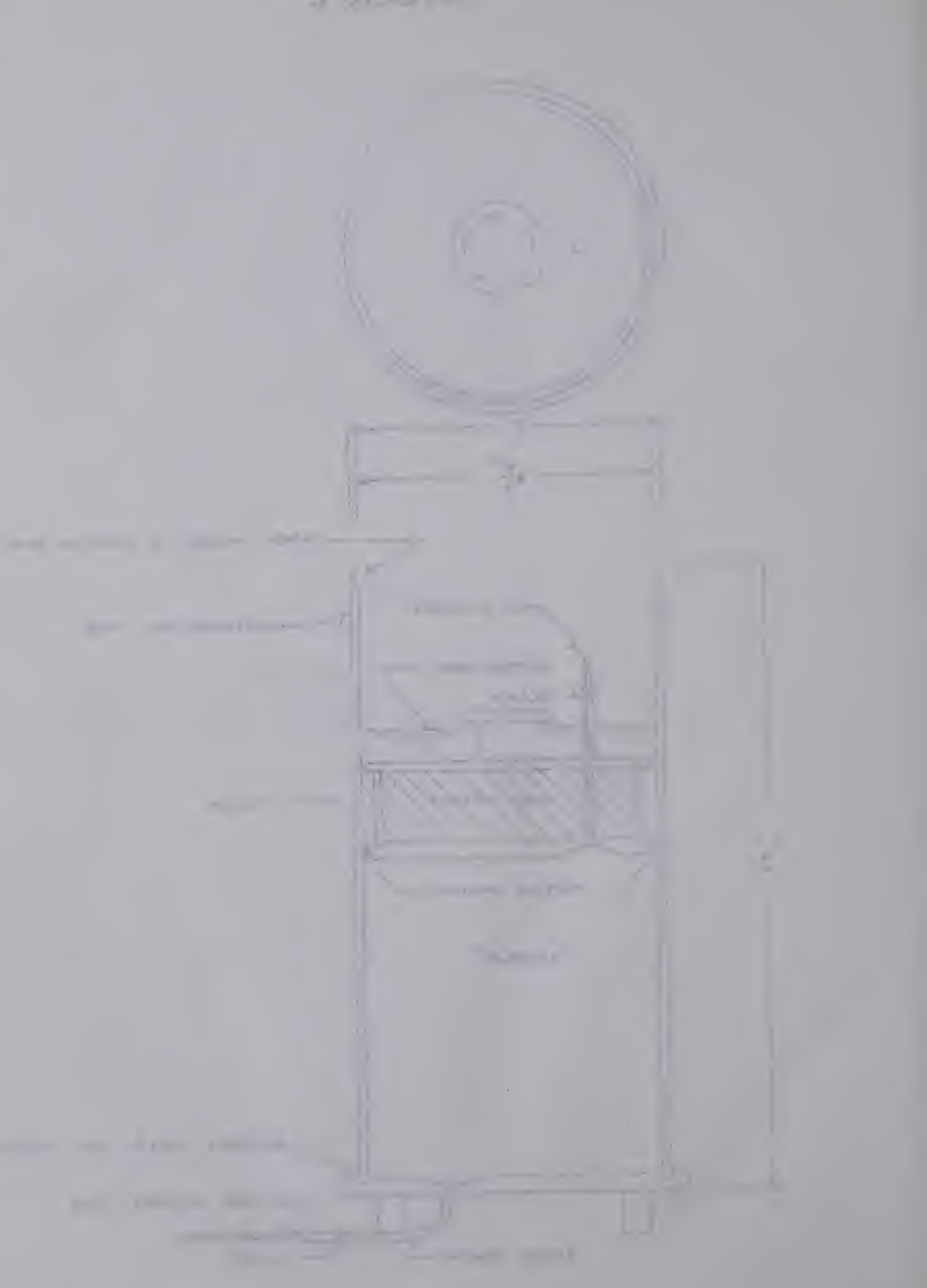
CONSTRUCTION DETAILS FOR

THE PERSPEX CYLINDER

APPENDIX C



CONSTRUCTION OF PERSPEX CYLINDER



B29844